Measuring the Mass and Spin of Dark Matter at a Lepton Collider

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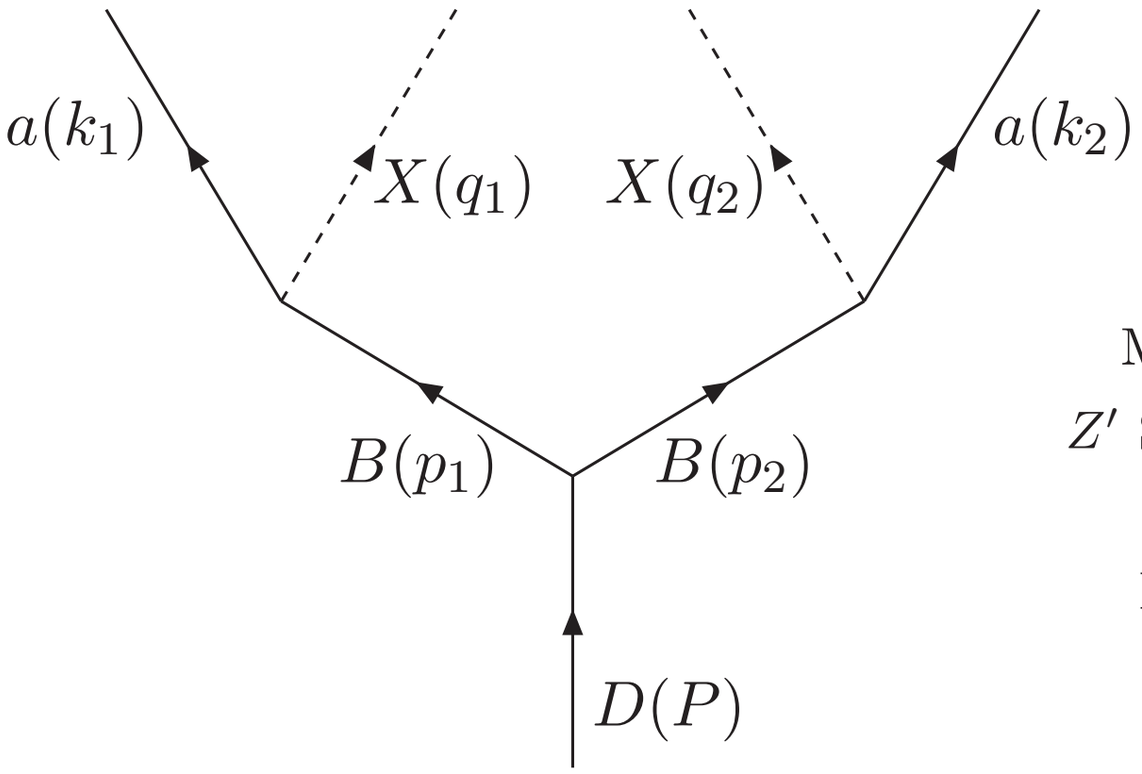
Dark Matter

- Existence of dark matter has been well established from astronomical observations.
- Dark matter is non-hadronic and electrically neutral making it difficult to measure its properties.
- Many possibilities for dark matter. WIMPs are well motivated.
- If sufficiently light, WIMPs could be produced at colliders.

Antlers



MSSM [7], $H \to \tilde{\chi}_2^0 + \tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0 + Z\tilde{\chi}_1^0$;

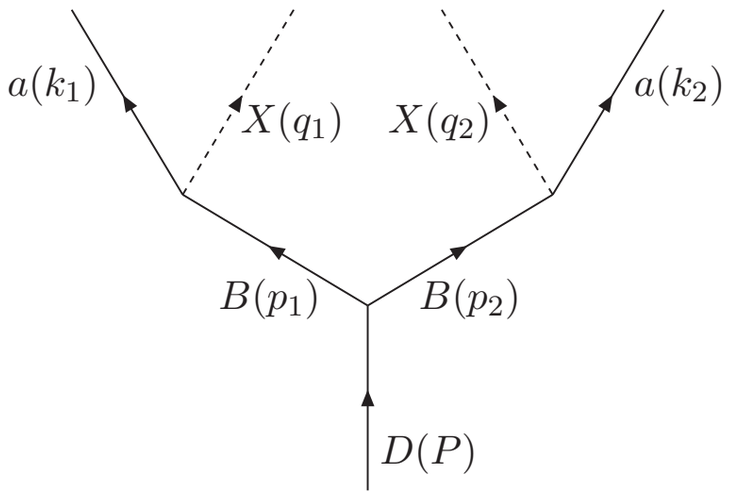
Z' SUSY [8], $Z' \to \tilde{\ell}^- + \tilde{\ell}^+ \to \ell^-\tilde{\chi}_1^0 + \ell^+\tilde{\chi}_1^0$;

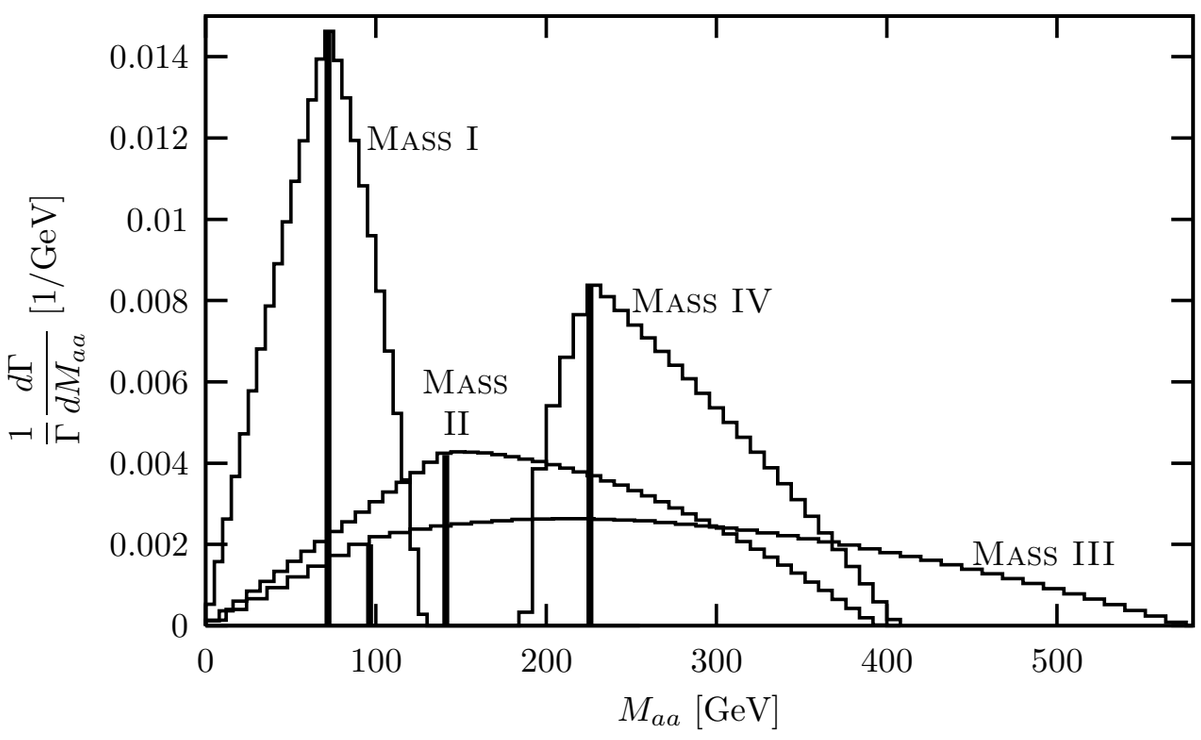
UED [9], $Z^{(2)} \to L^{(1)} + L^{(1)} \to \ell^-\gamma^{(1)} + \ell^+\gamma^{(1)}$;

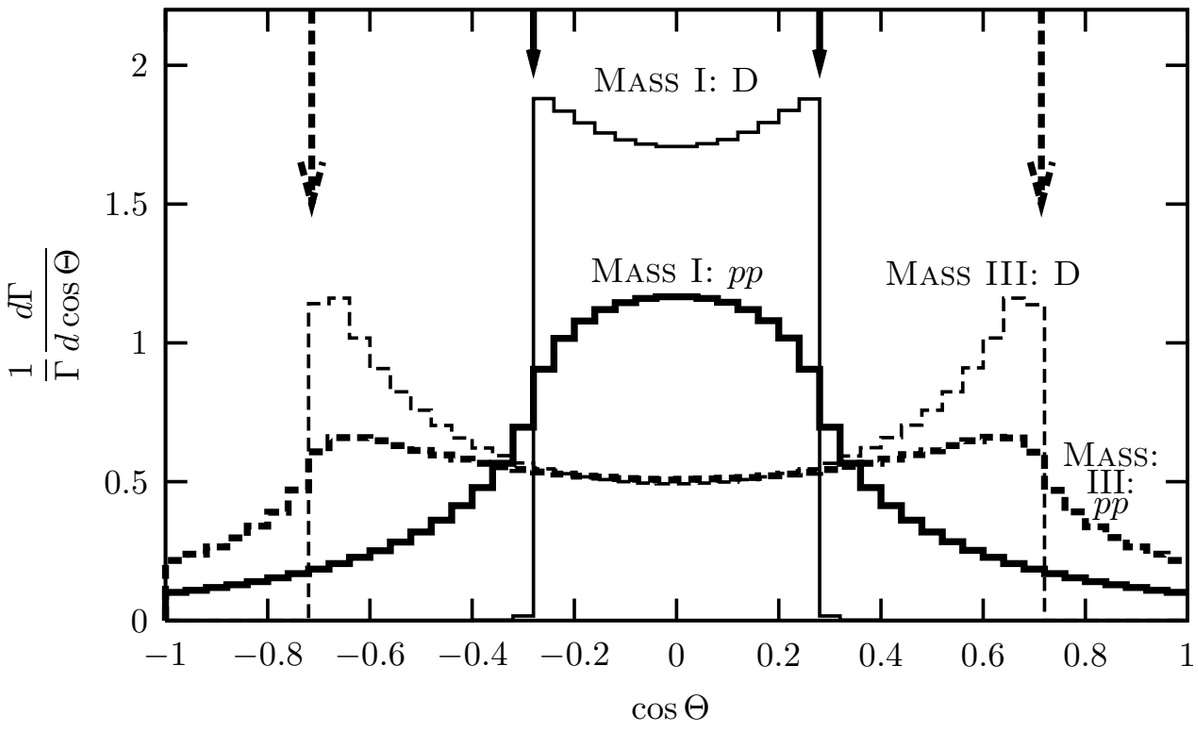
LHT [10], $H \to t_- + t_- \to tA_H + tA_H$.

arXiv:0906.5009
Han, Kim, Song

Kinematic Cusps & Endpoints

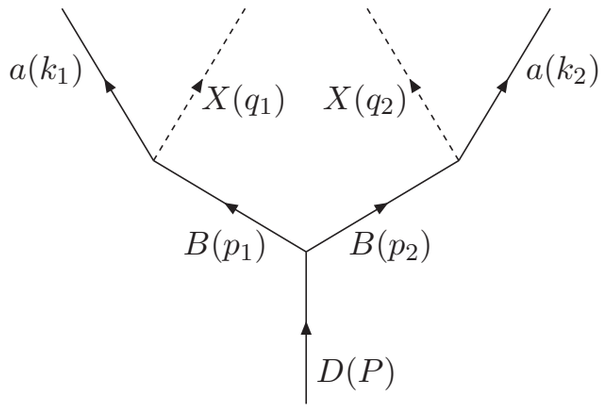


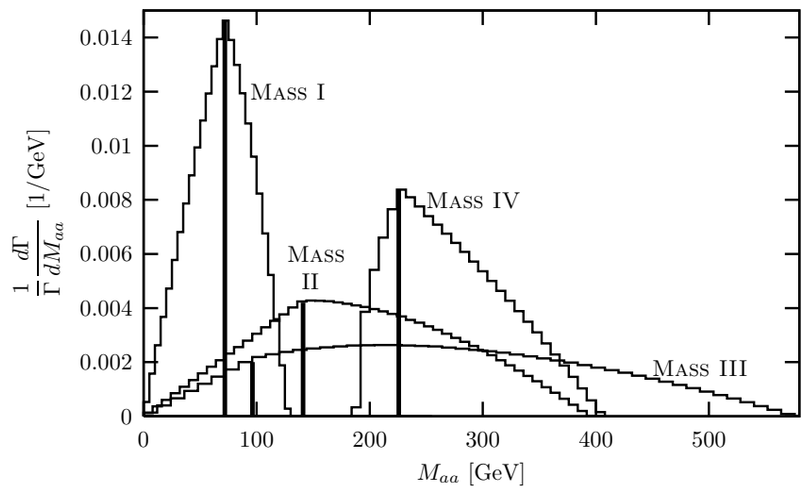


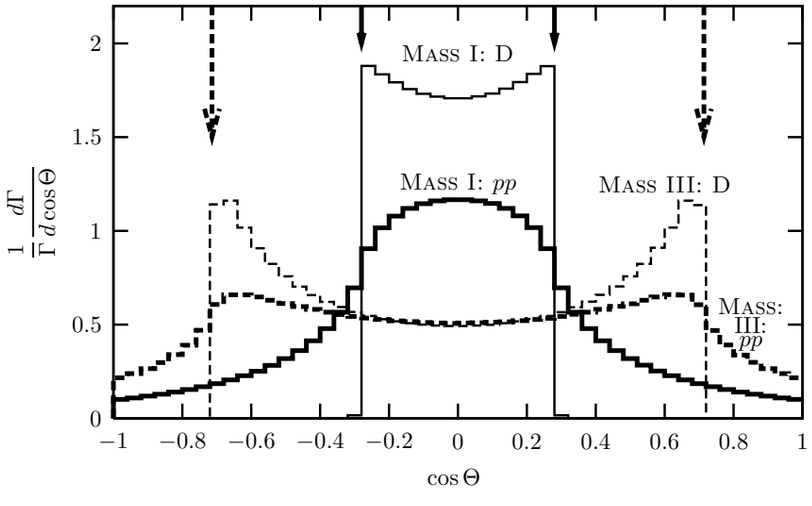


arXiv:0906.5009

Kinematic Cusps & Endpoints Challenges

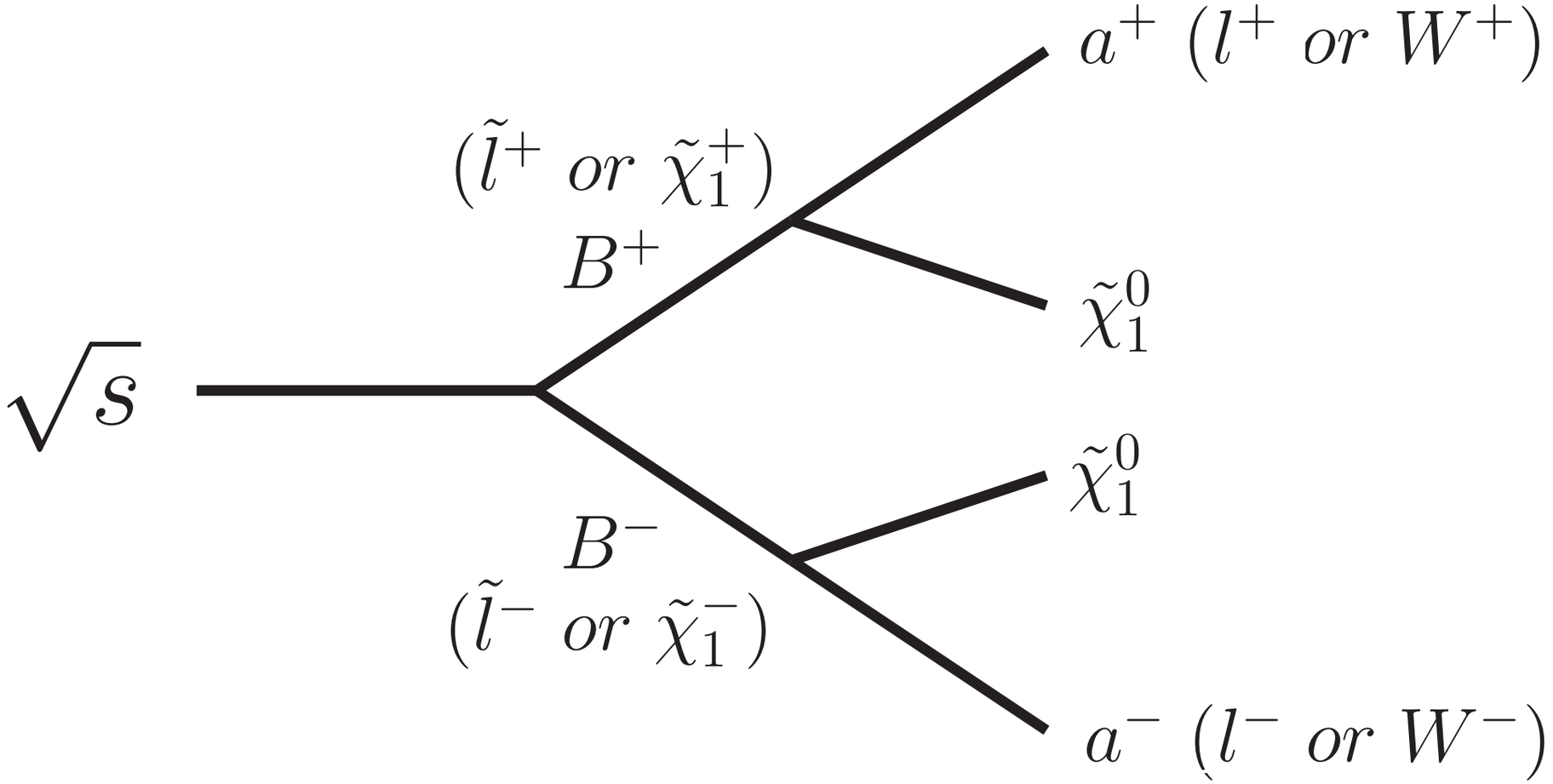




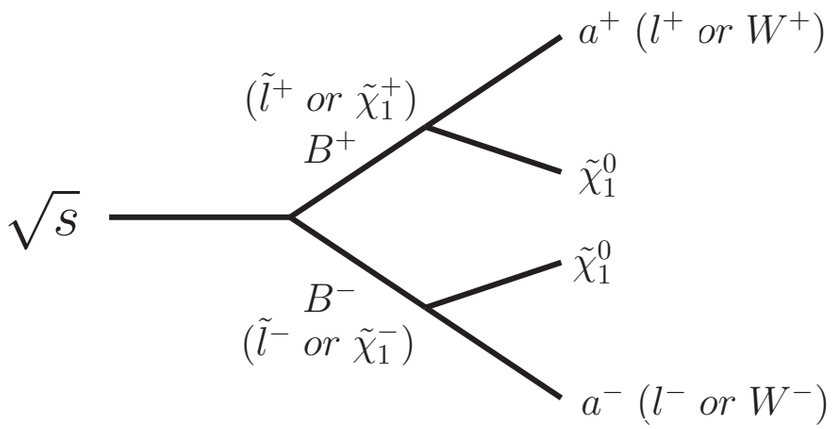


- D→B→a may not be possible.
  - Ex: h may be too light for $h \to 2\tilde{l} \to 2\tilde{\chi}_1^0 + 2a$
- Cusps or endpoints could be difficult to measure.
  - Ex. M_{aa}~M_Z
  - Ex. M_{aa}~0GeV
- cos θ smeared by boost of collision frame.

Antlers at Lepton Colliders



Following slides preliminary: To be published soon:
Christensen, Han, Song, Stefanus



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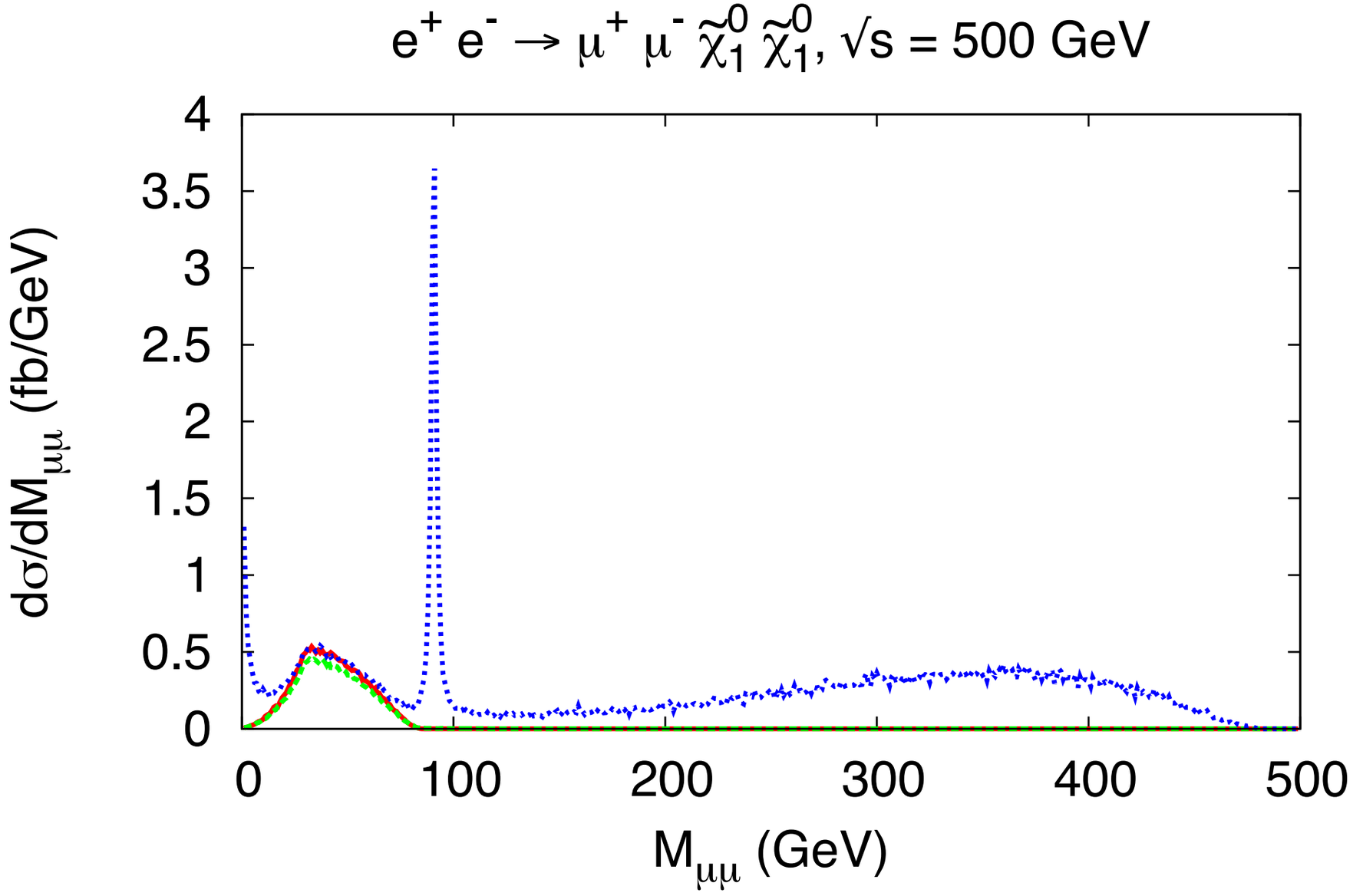

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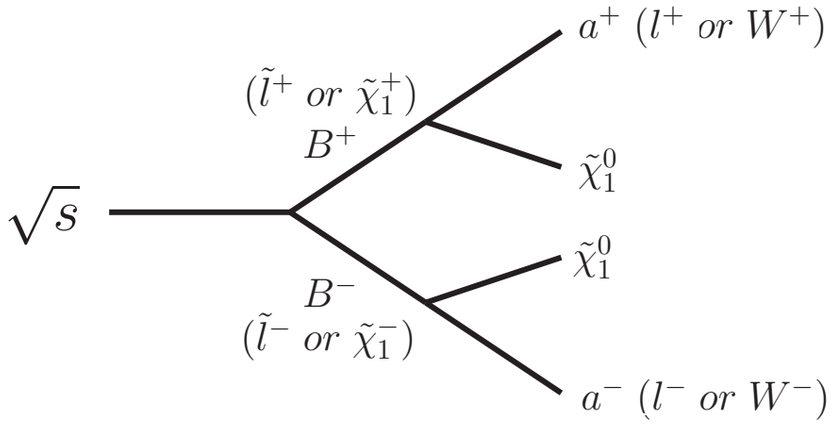

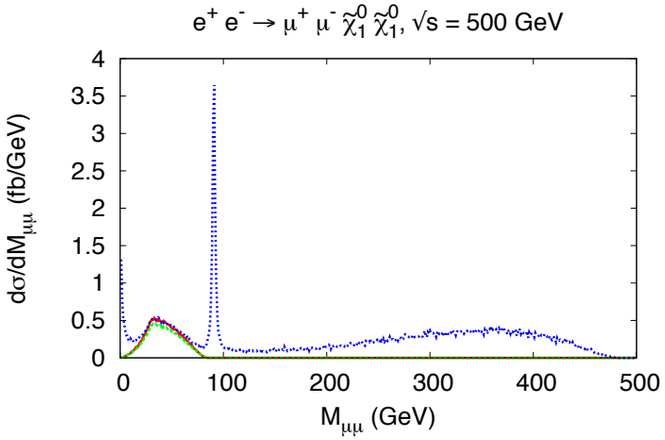

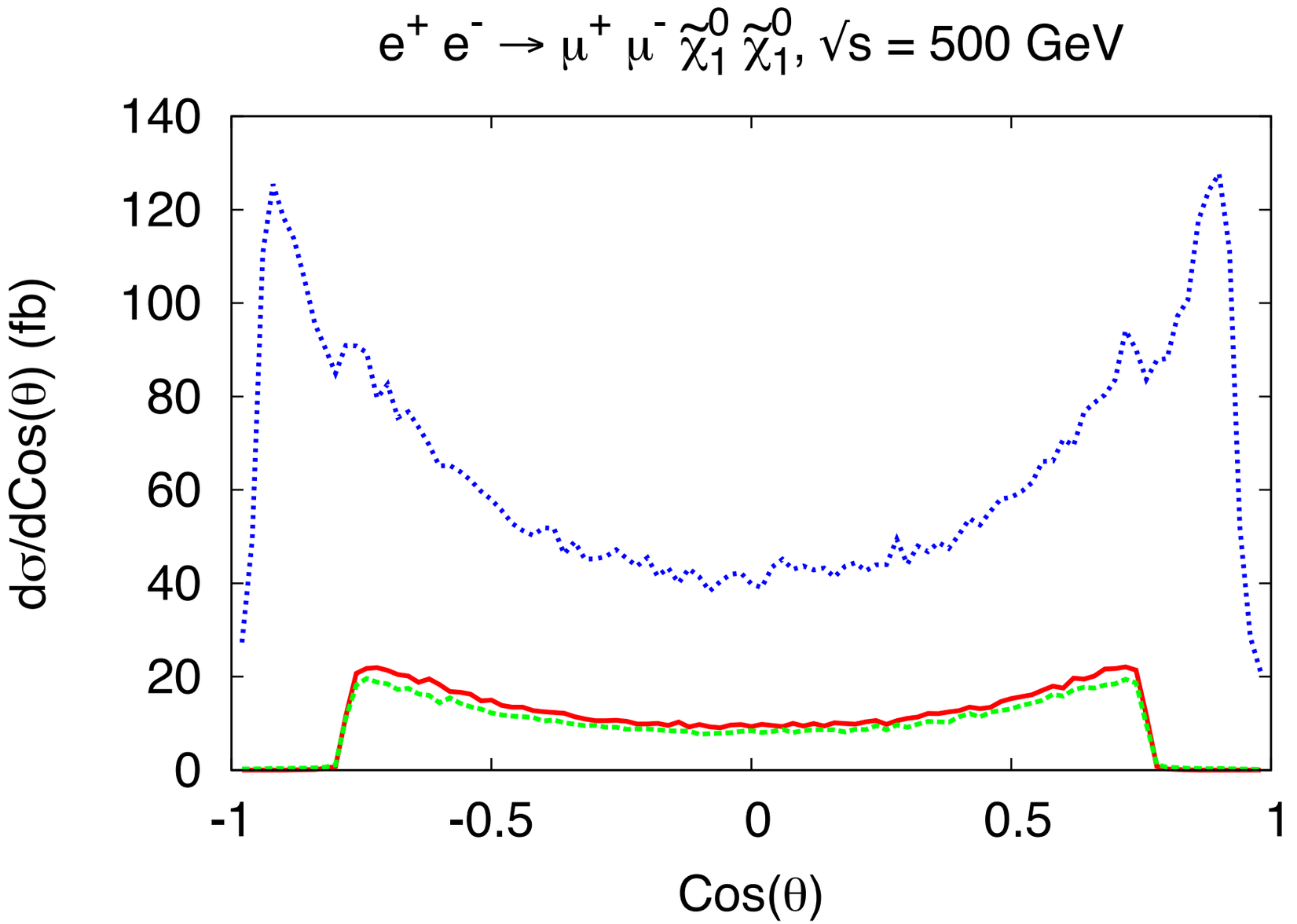

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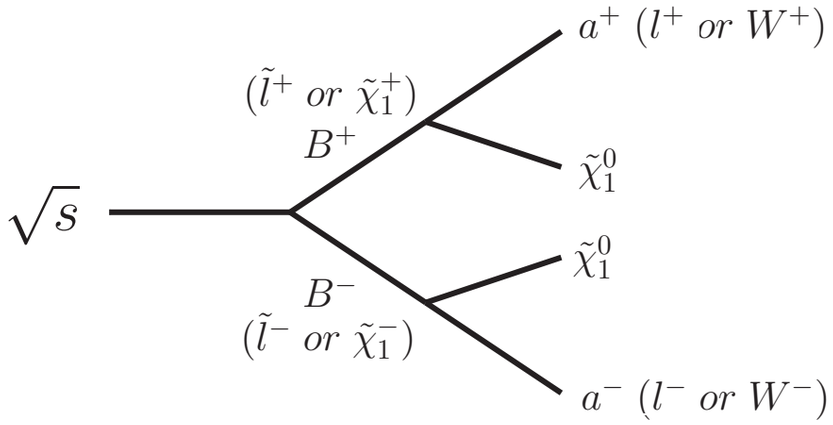

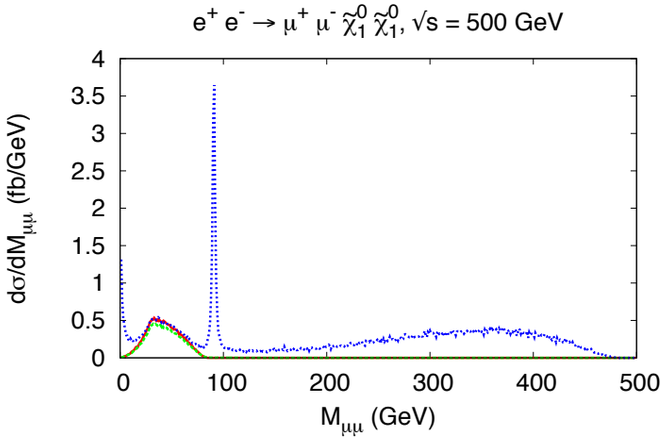

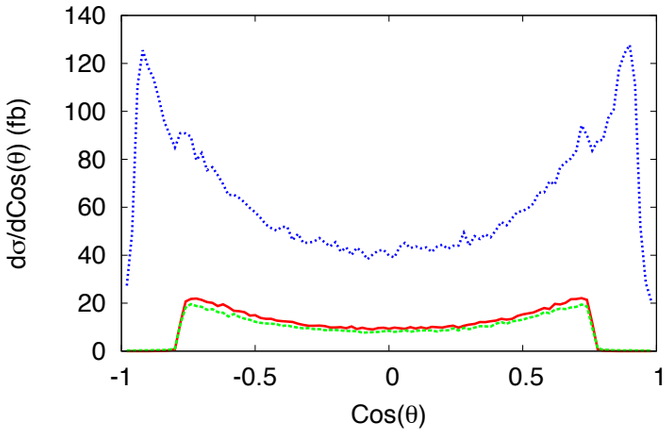

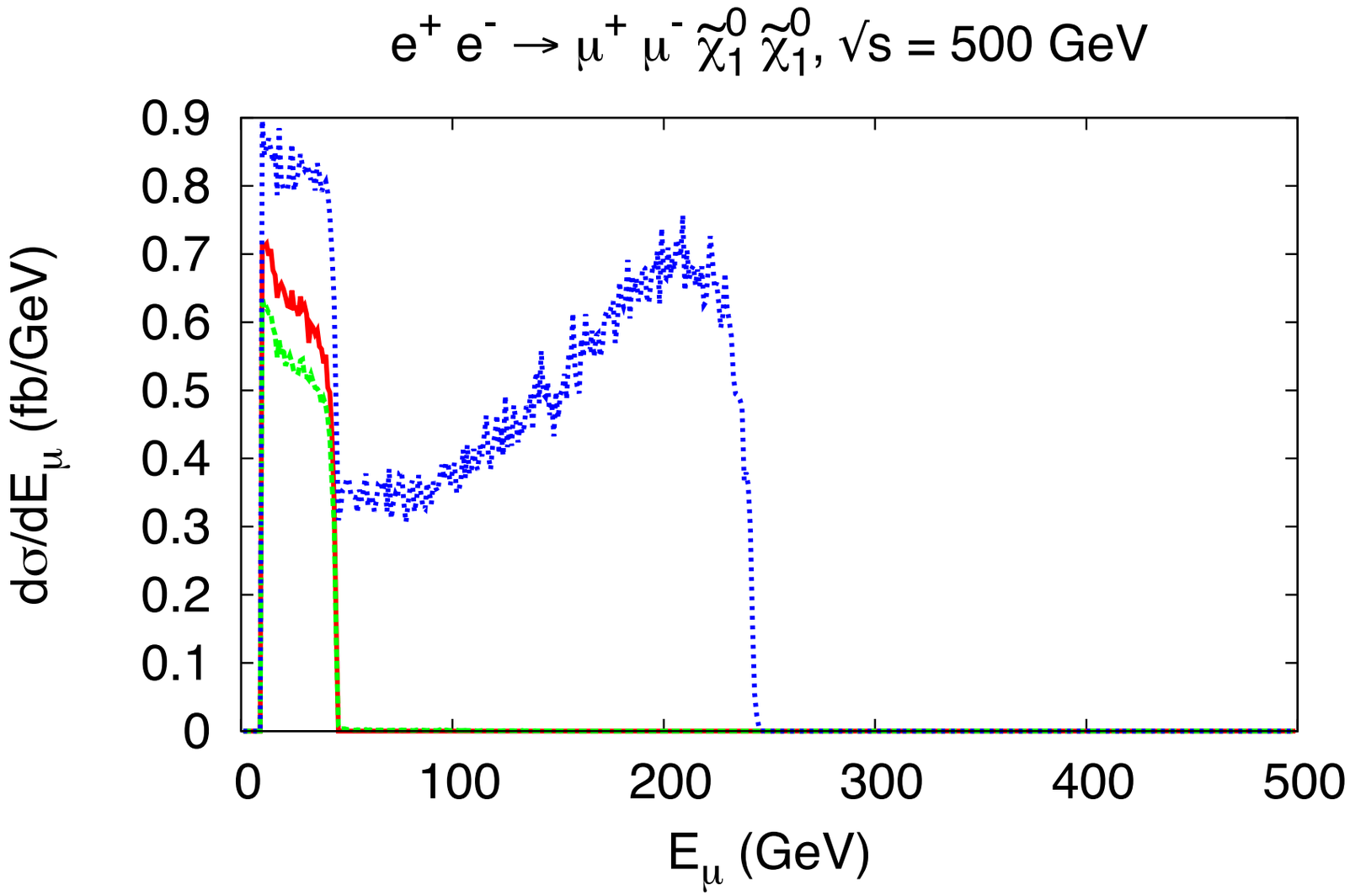

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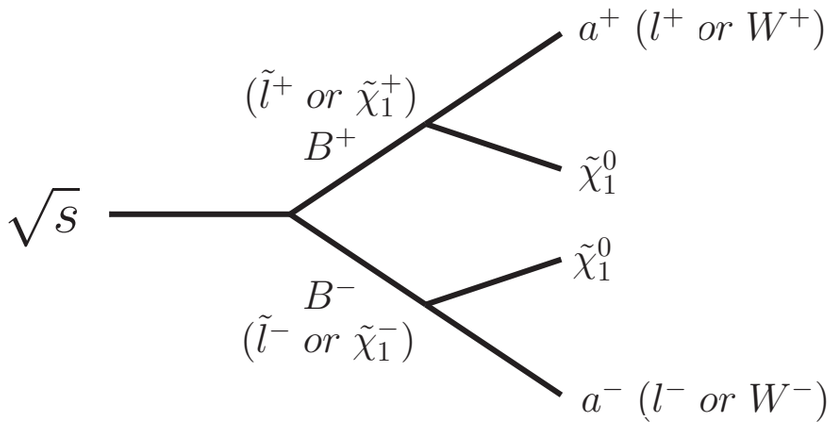
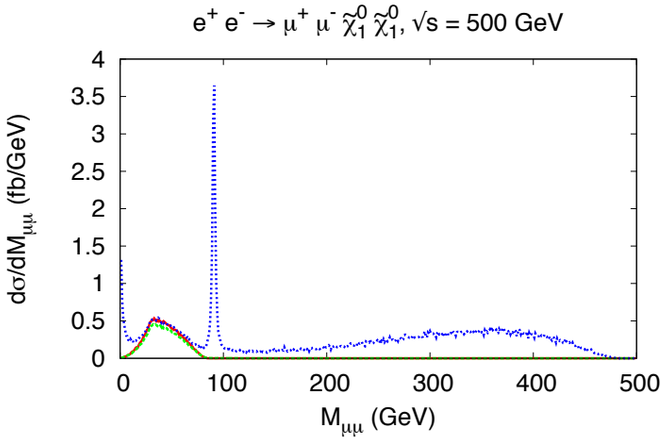
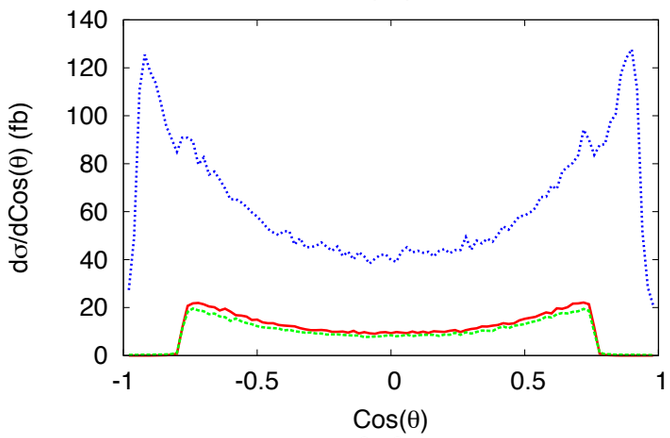
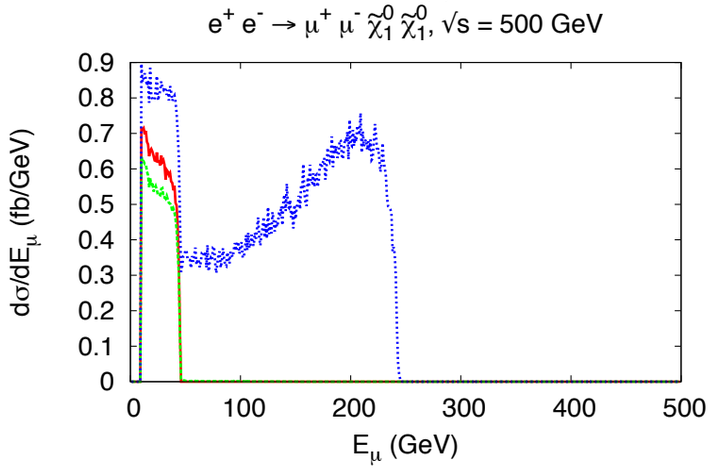


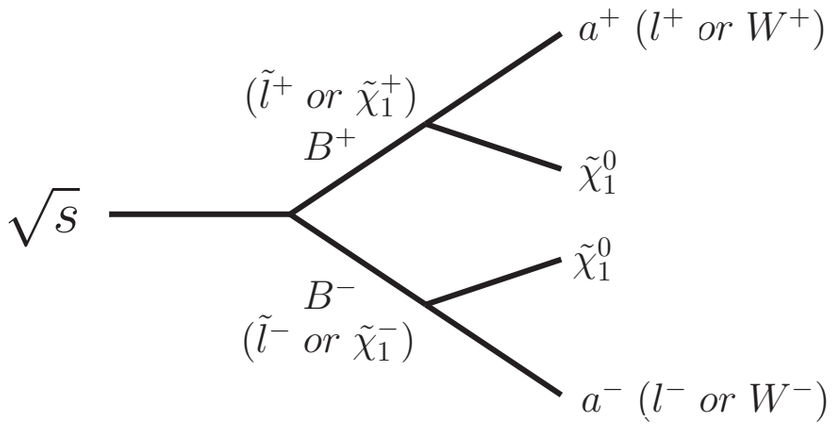


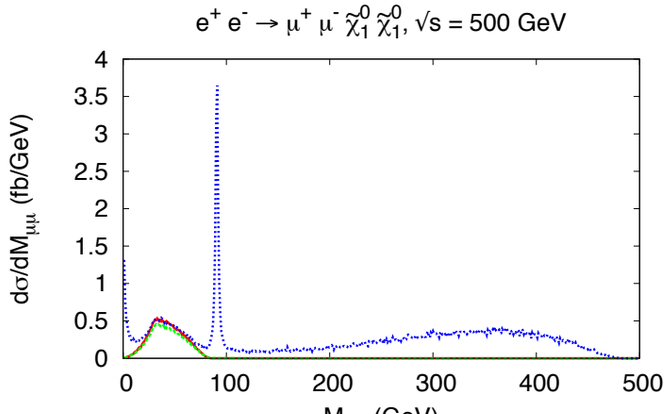


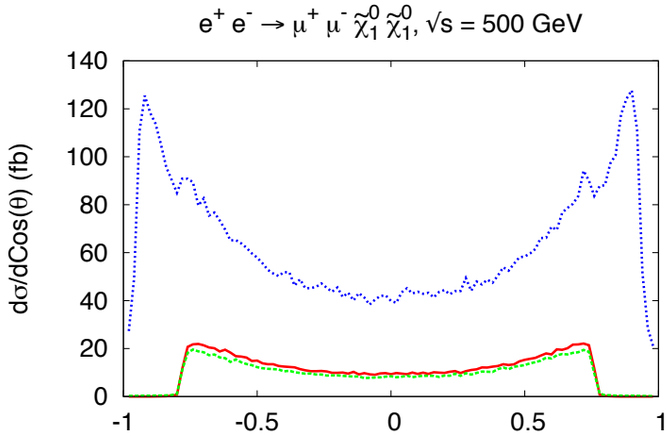


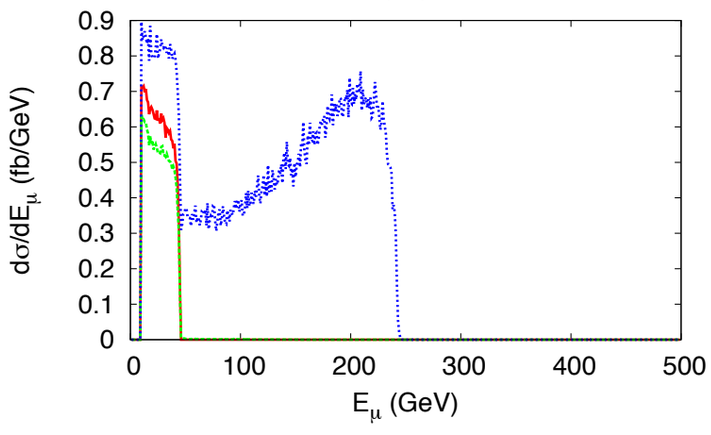
$$m_{rec}^2 \equiv m_{\tilde{\chi}_1^0\tilde{\chi}_1^0}^2 = s - 2\sqrt{s}\,(E_{a_1} + E_{a_2}) + m_{aa}^2$$

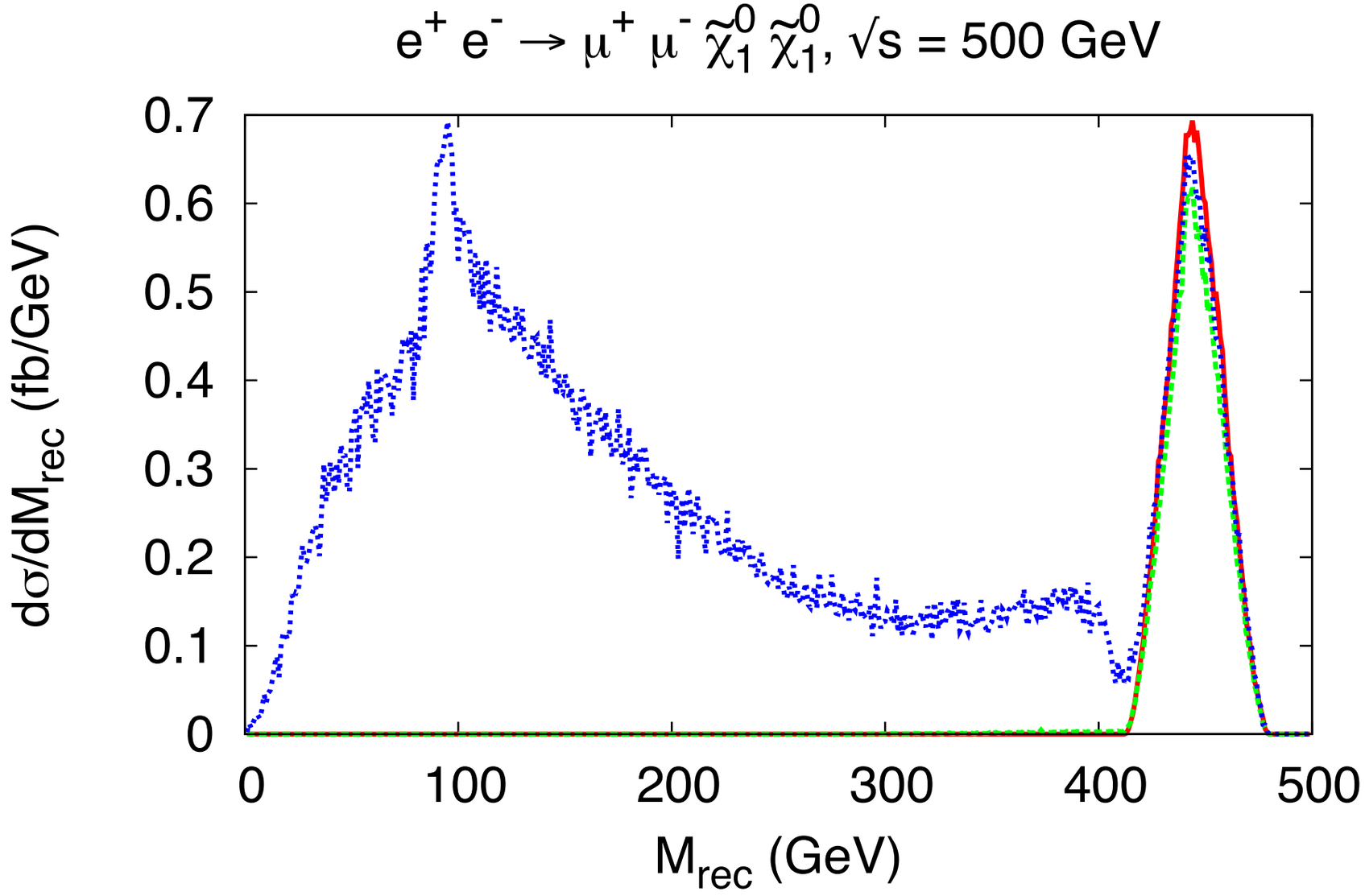
Antlers at Lepton Colliders



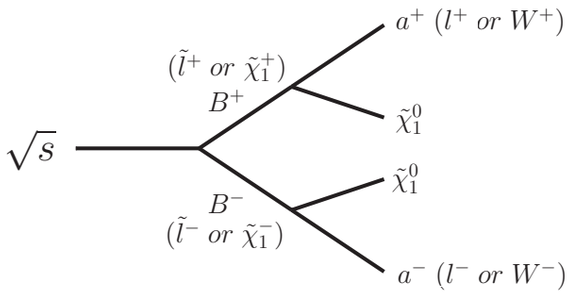


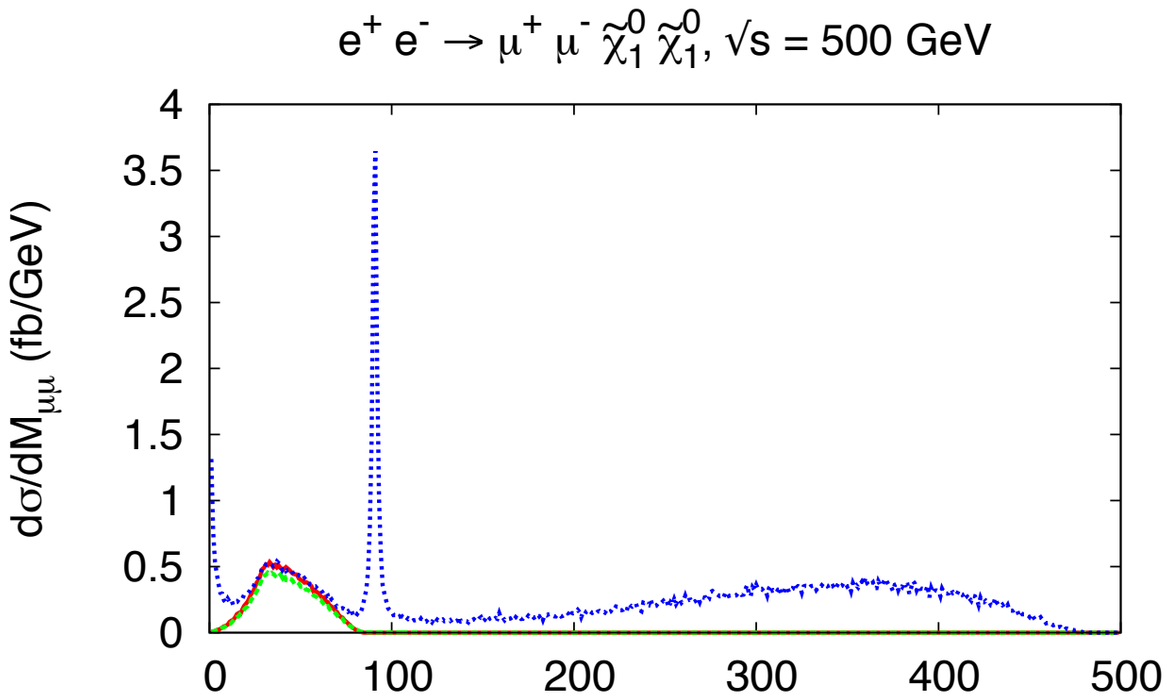


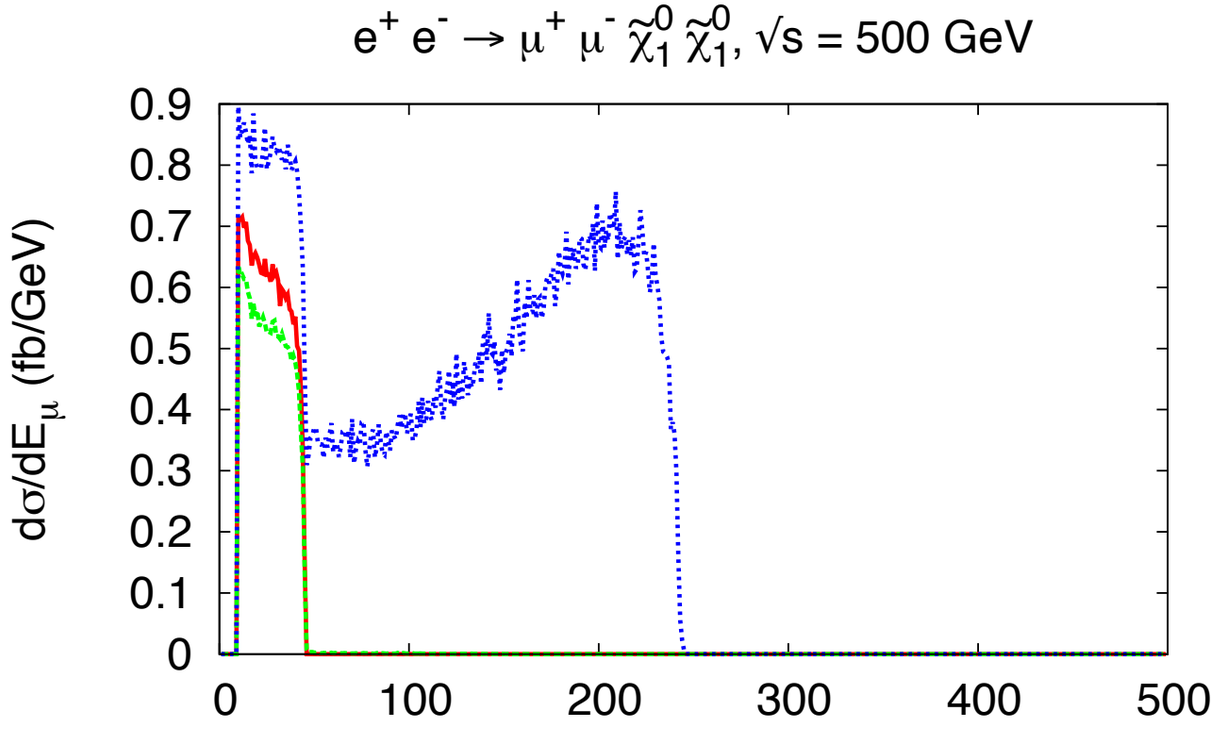


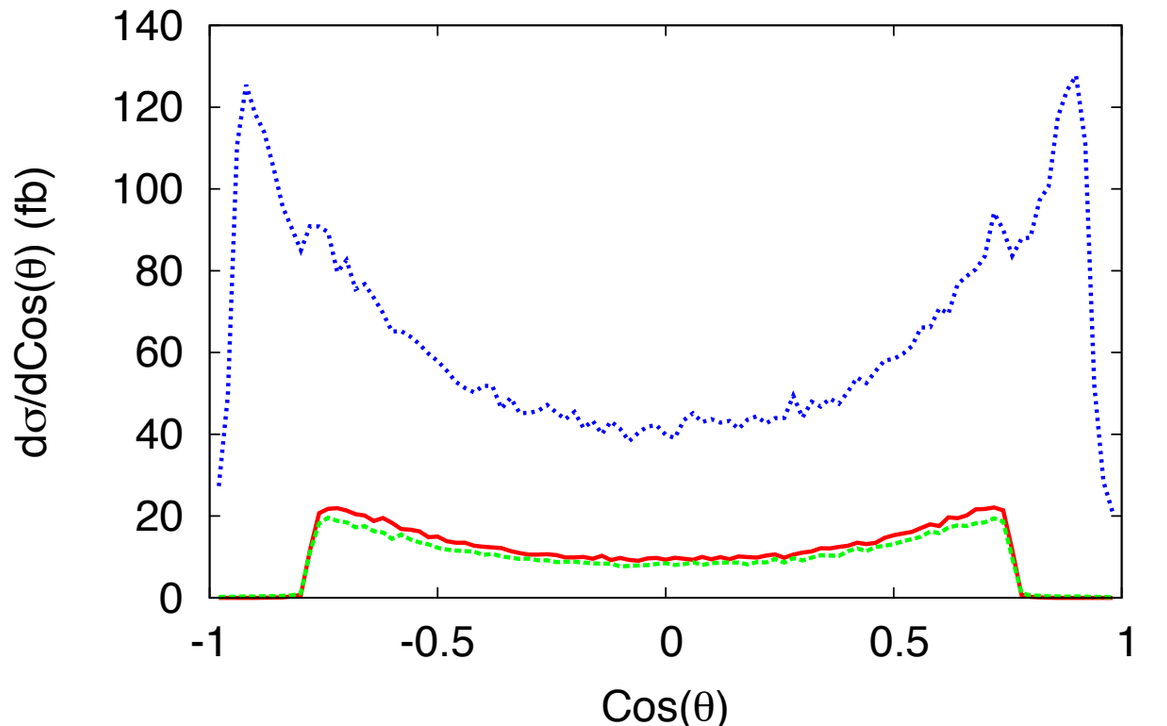


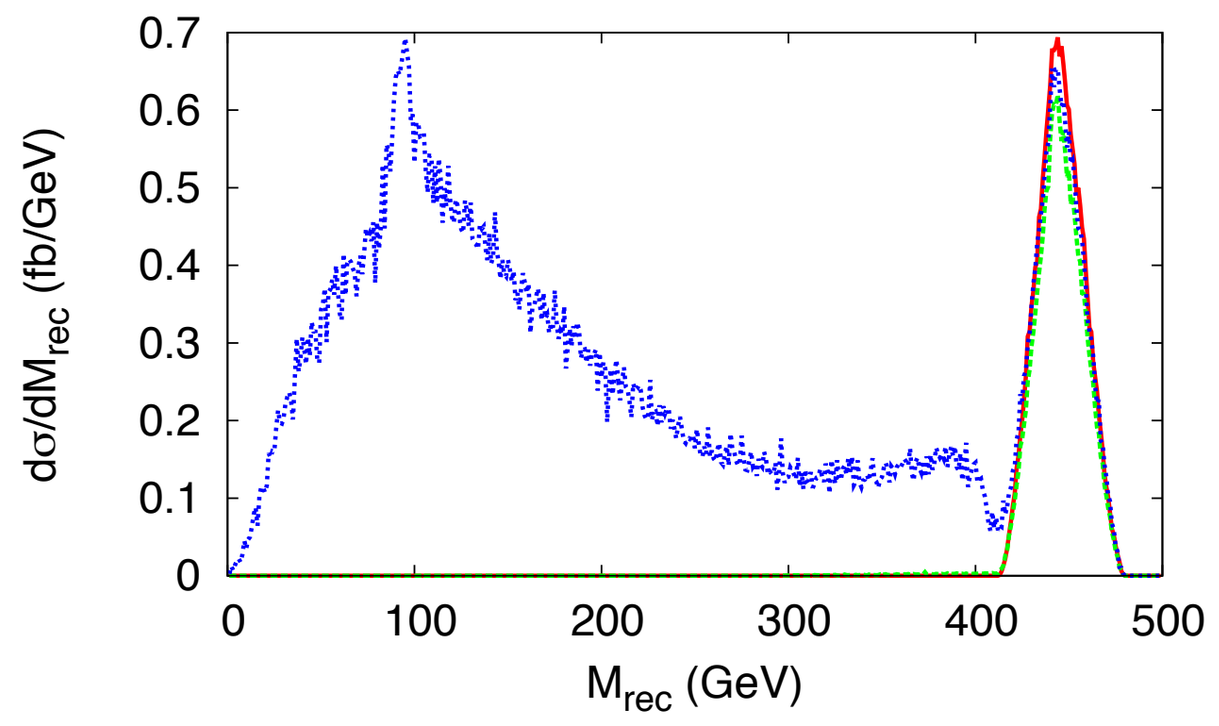
Antlers at Lepton Colliders

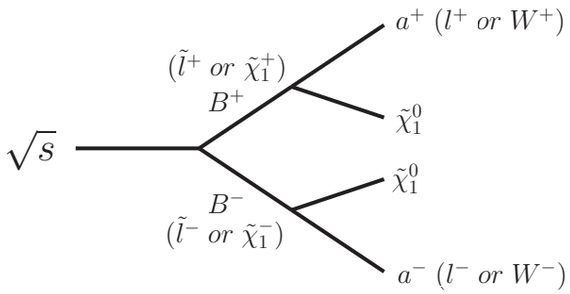




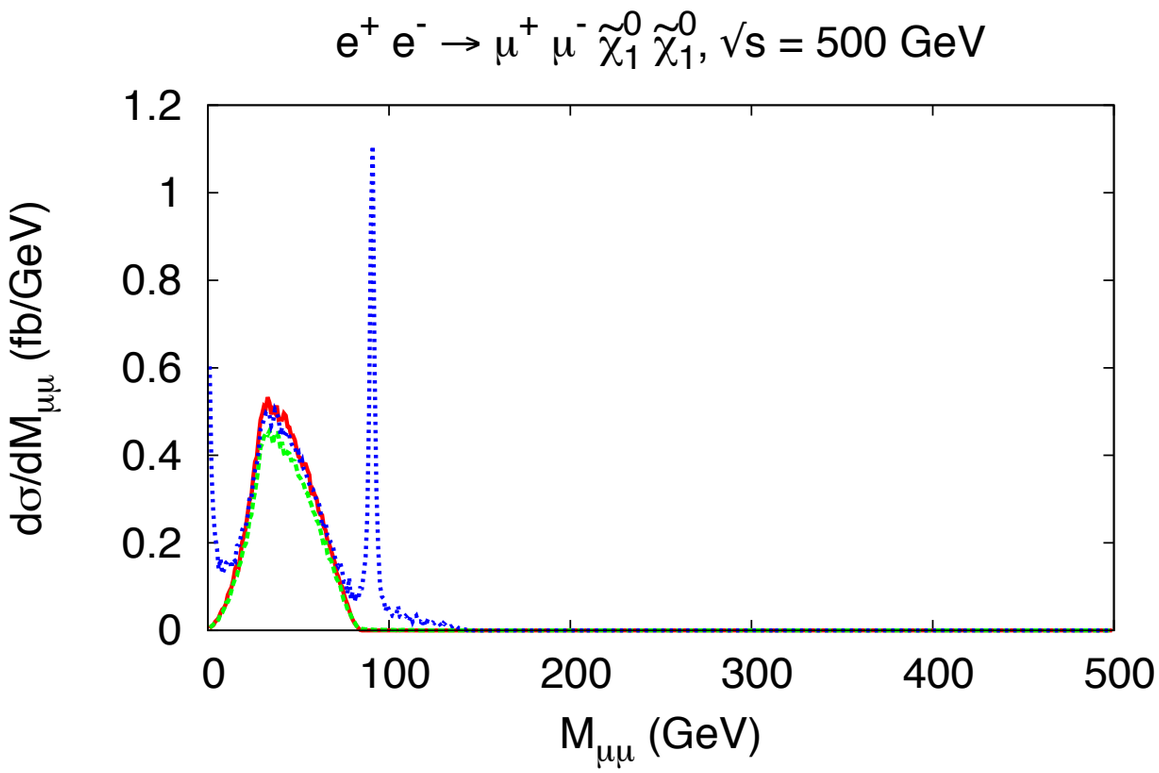


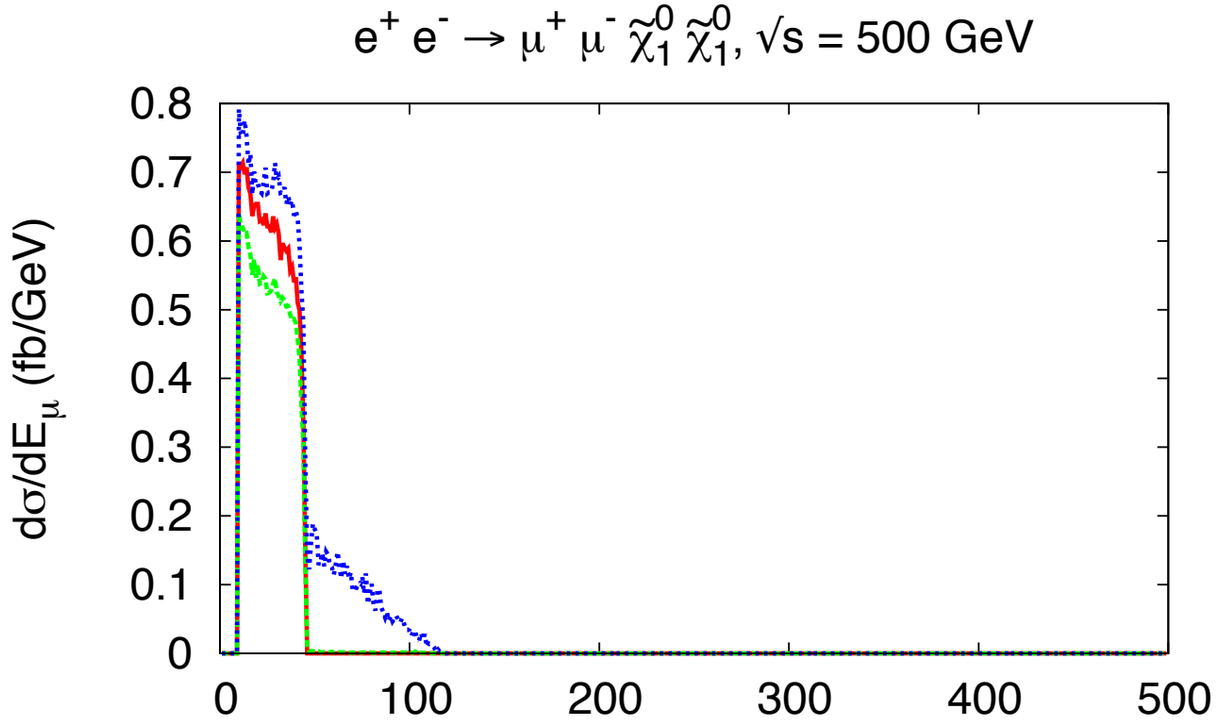


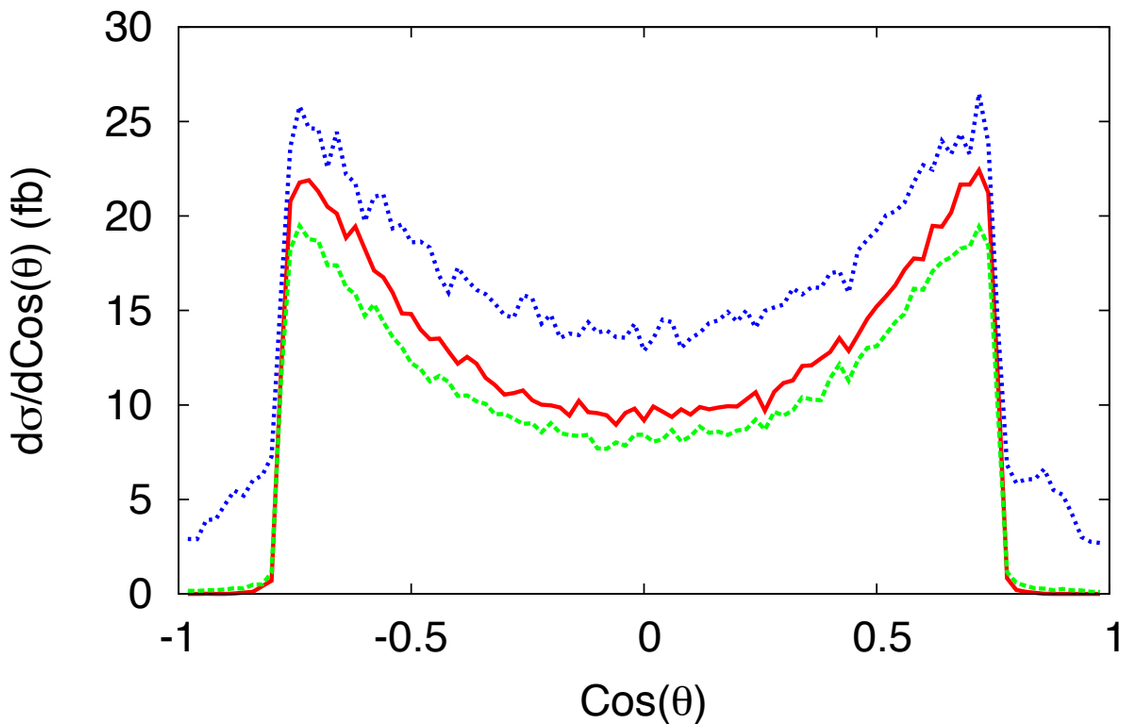


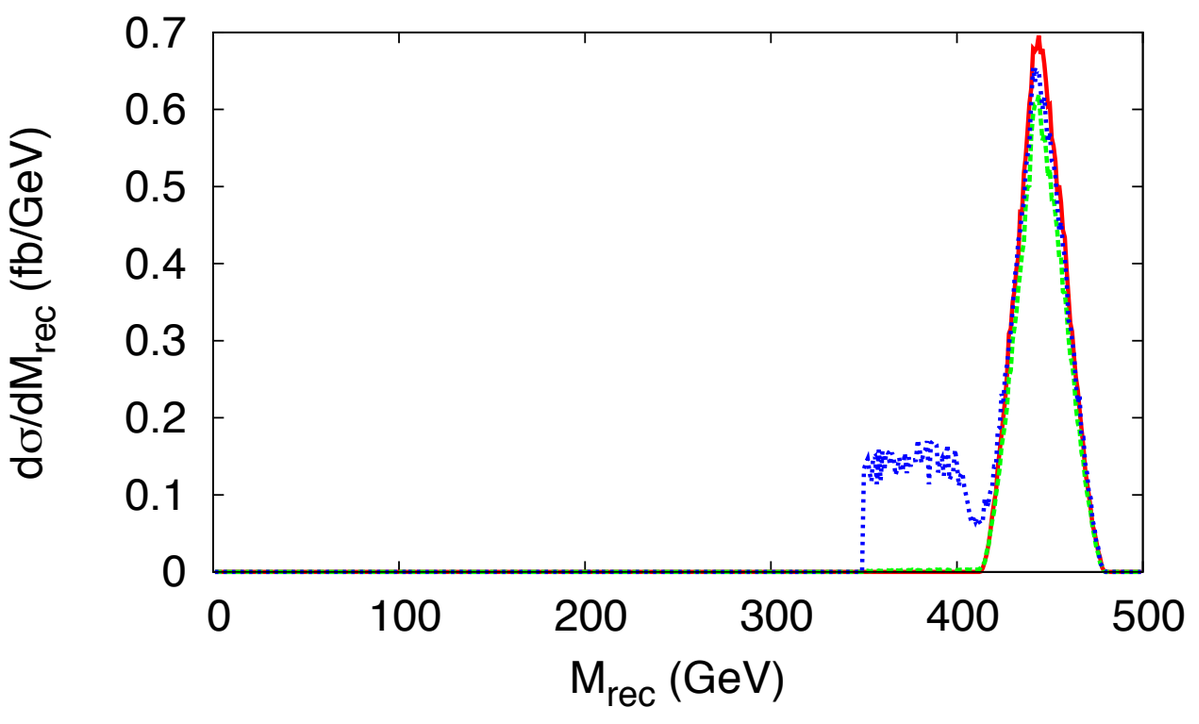


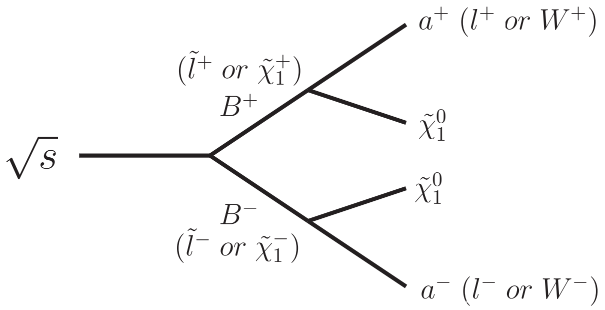
$m_{\mathrm{rec}} \geq 350\mathrm{GeV}$



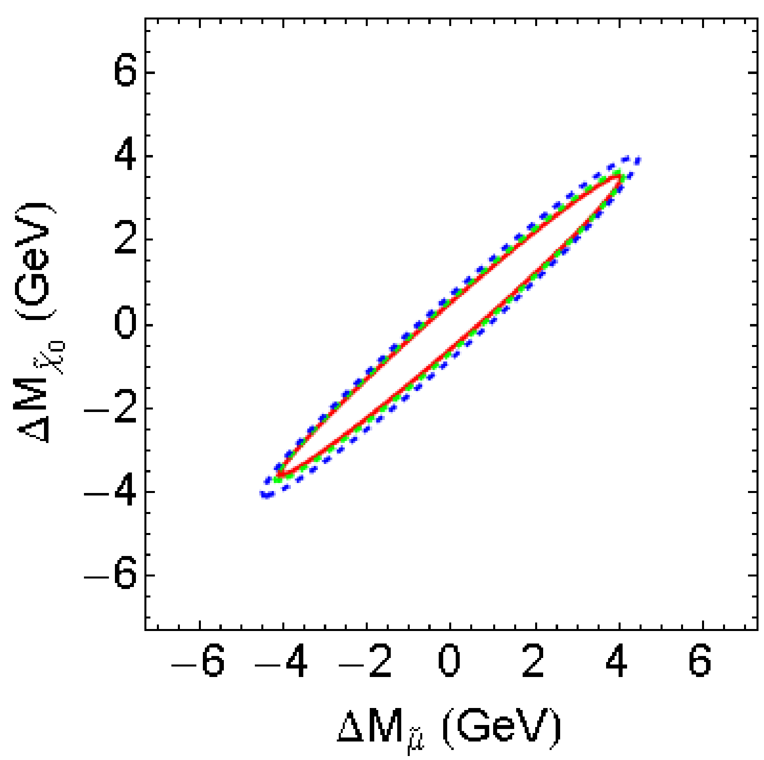


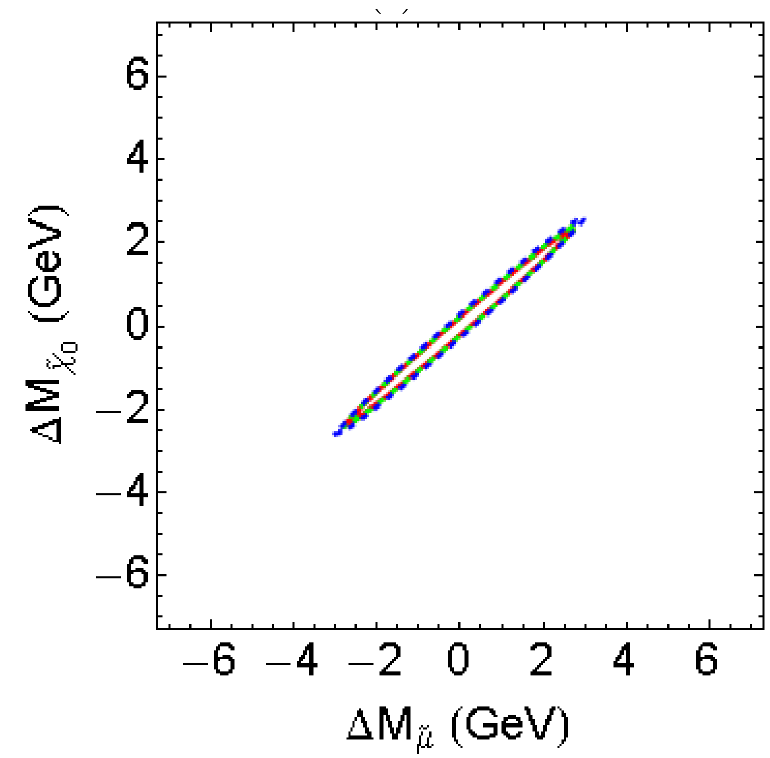





a^+ (l^+ or W^+)
($\tilde{l}^+$ or $\tilde{\chi}_1^+$)
B^+
$\tilde{\chi}_1^0$
$\sqrt{s}$
$\tilde{\chi}_1^0$
B^-
($\tilde{l}^-$ or $\tilde{\chi}_1^-$)
a^- (l^- or W^-)

95% CL : 100fb^{-1}


$\Delta M_{\tilde{\chi}_0}$ (GeV)
$\Delta M_{\tilde{\mu}}$ (GeV)


$\Delta M_{\tilde{\chi}_0}$ (GeV)
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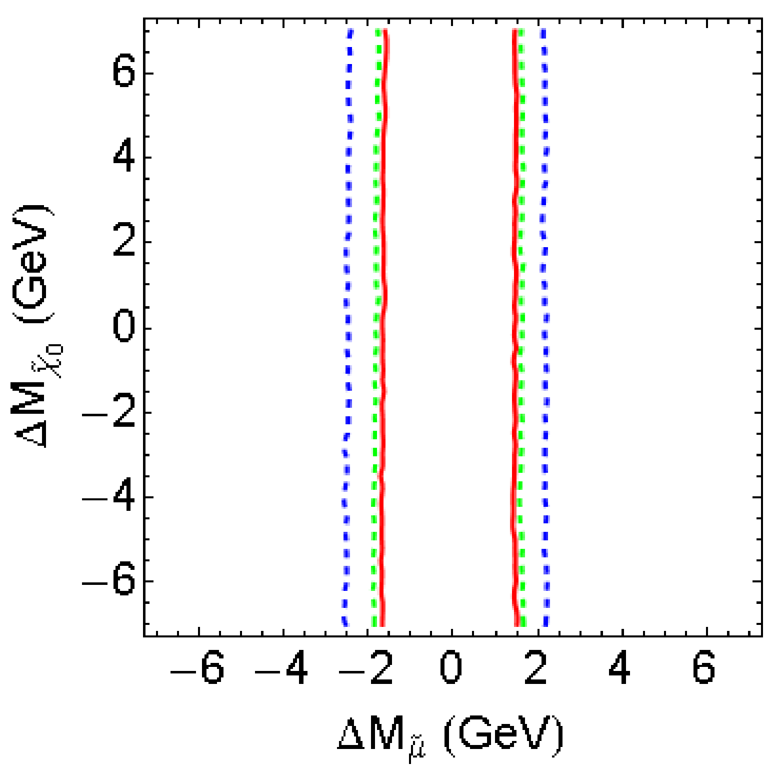
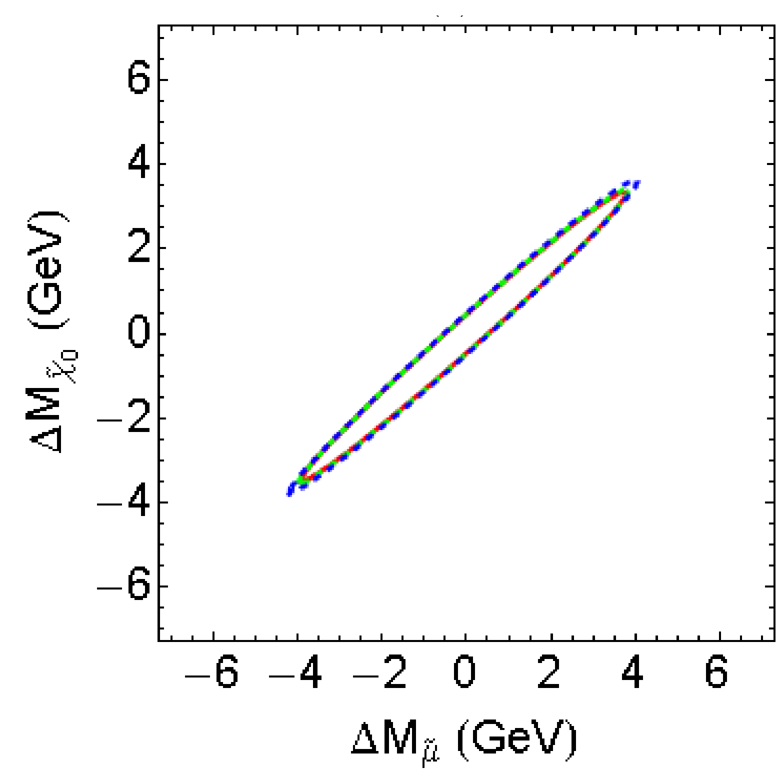

$\Delta M_{\tilde{\chi}_0}$ (GeV)
$\Delta M_{\tilde{\mu}}$ (GeV)


$\Delta M_{\tilde{\chi}_0}$ (GeV)
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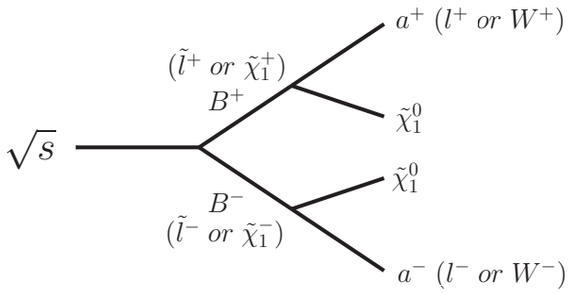
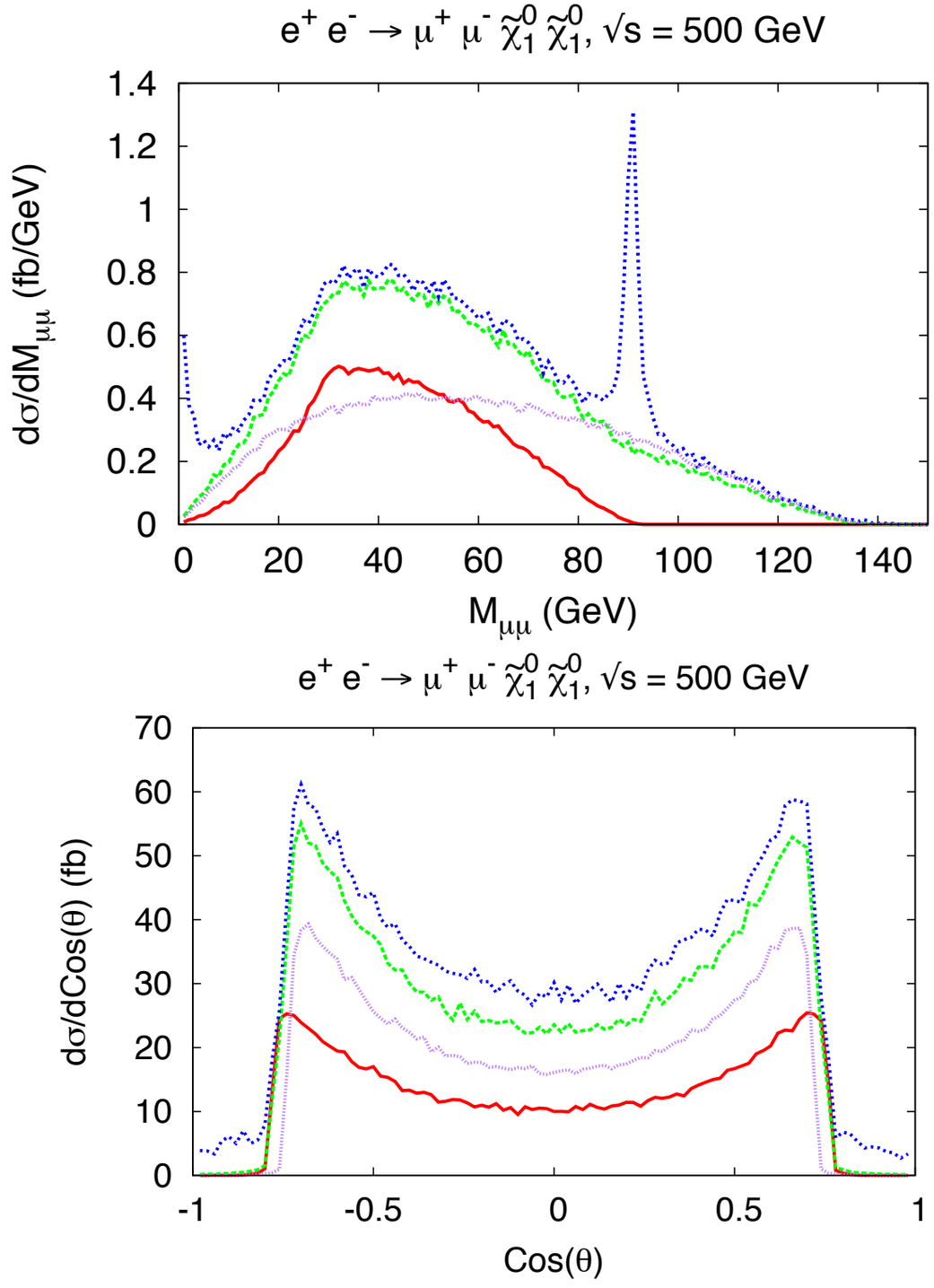
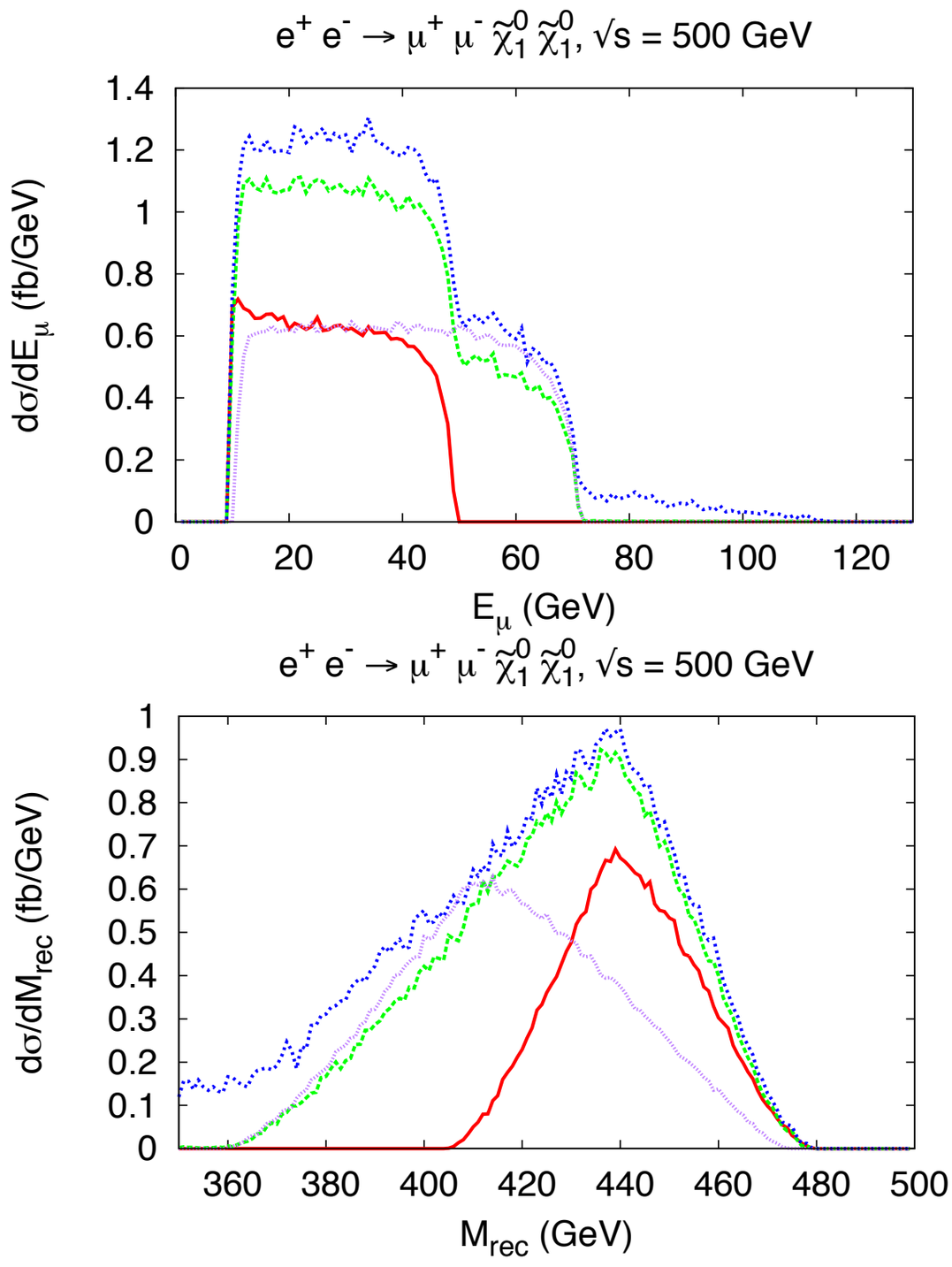
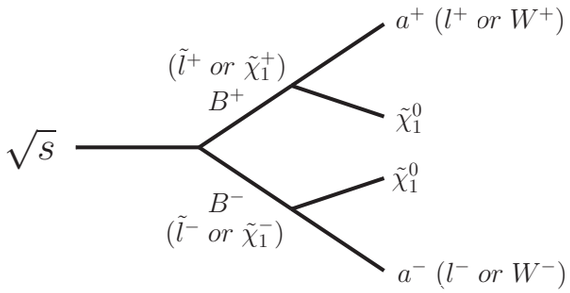


$$m_{\tilde{l}_L} \sim m_{\tilde{l}_R}$$

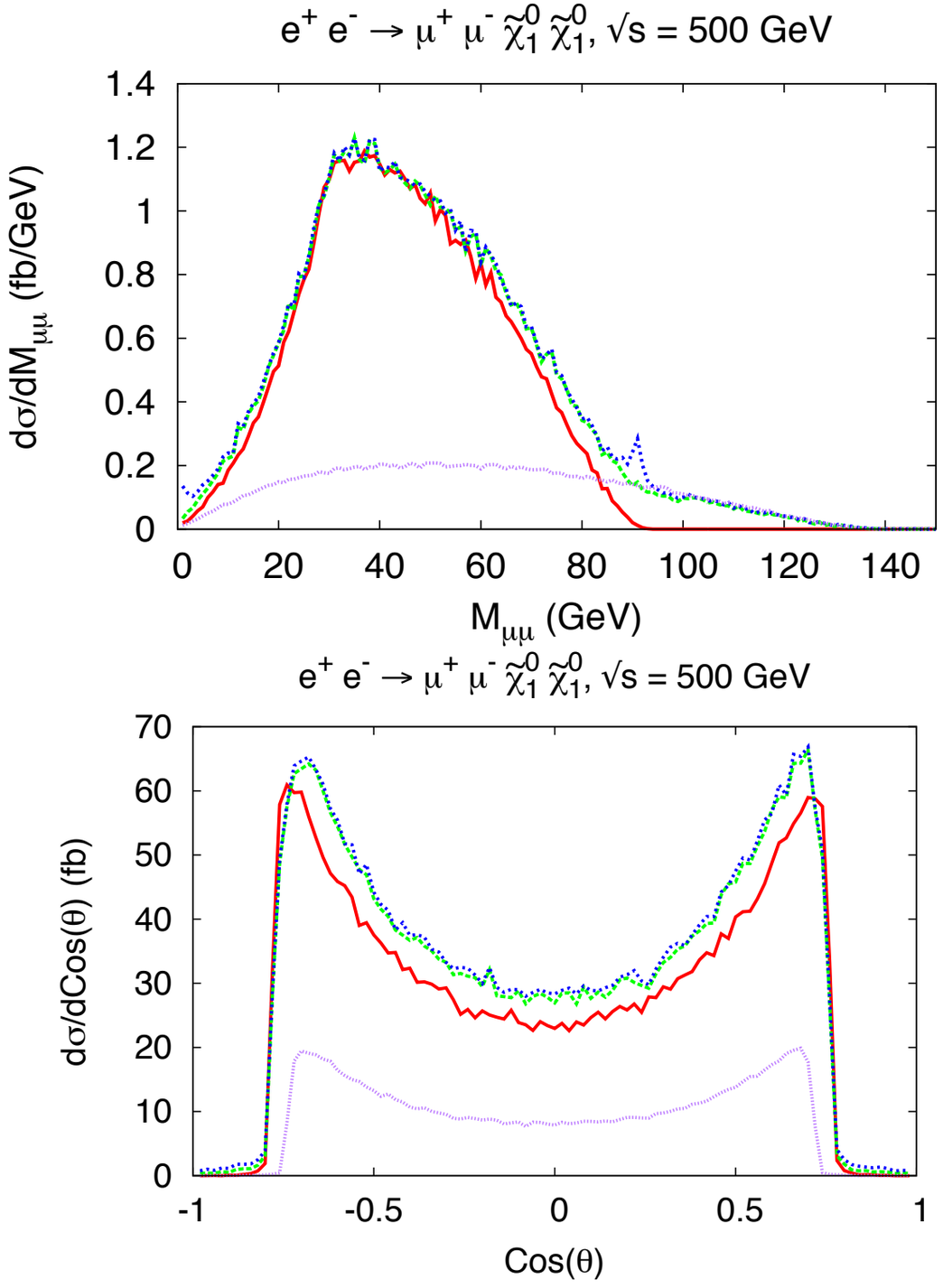


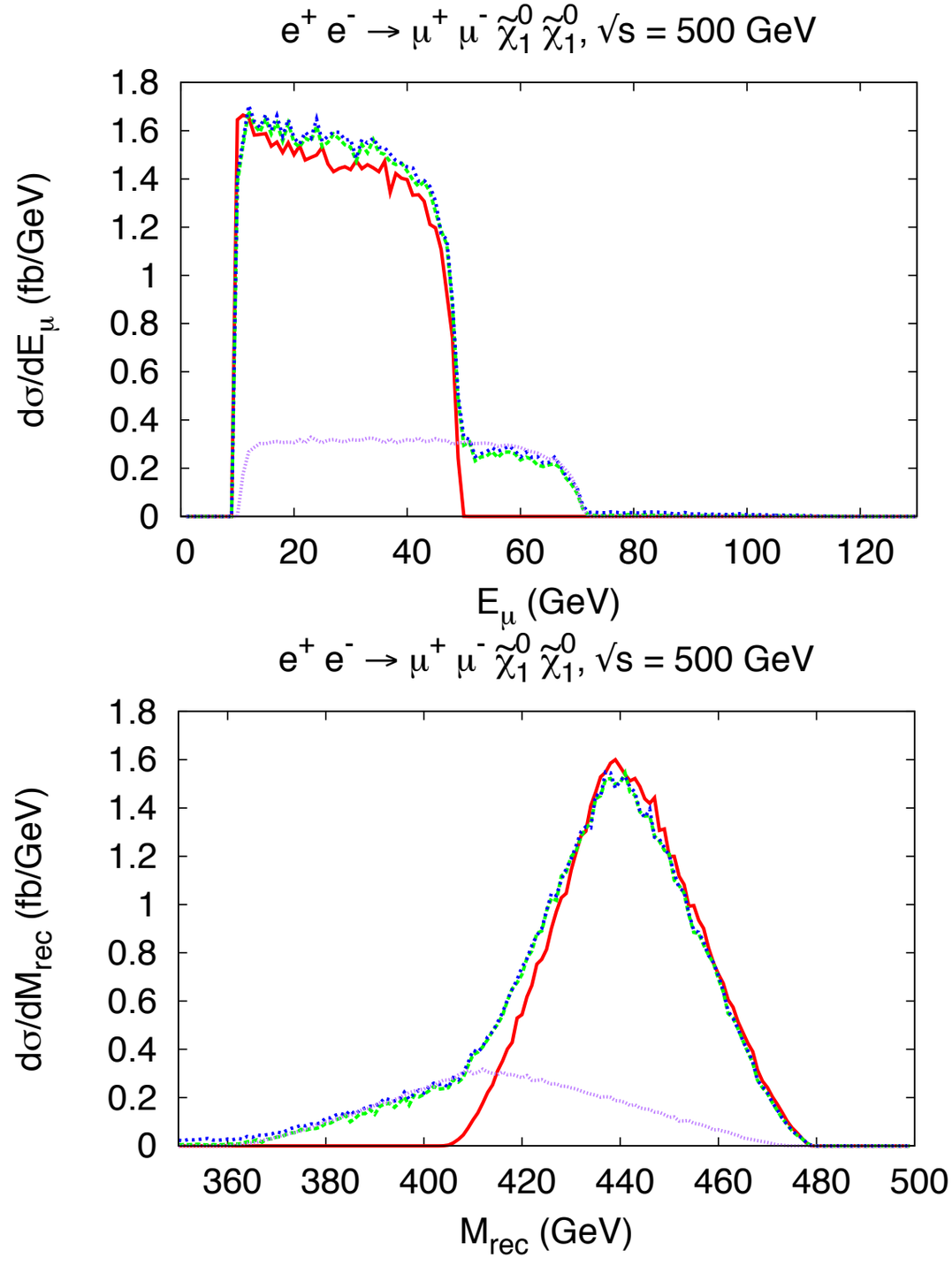


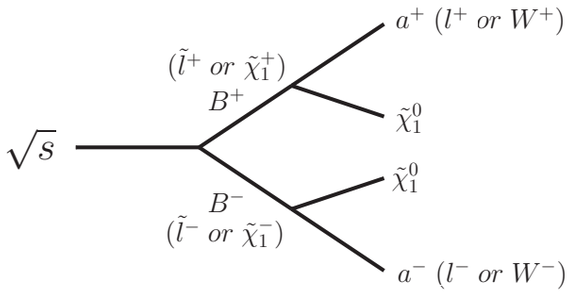


$$m_{\tilde{l}_L} \sim m_{\tilde{l}_R}$$

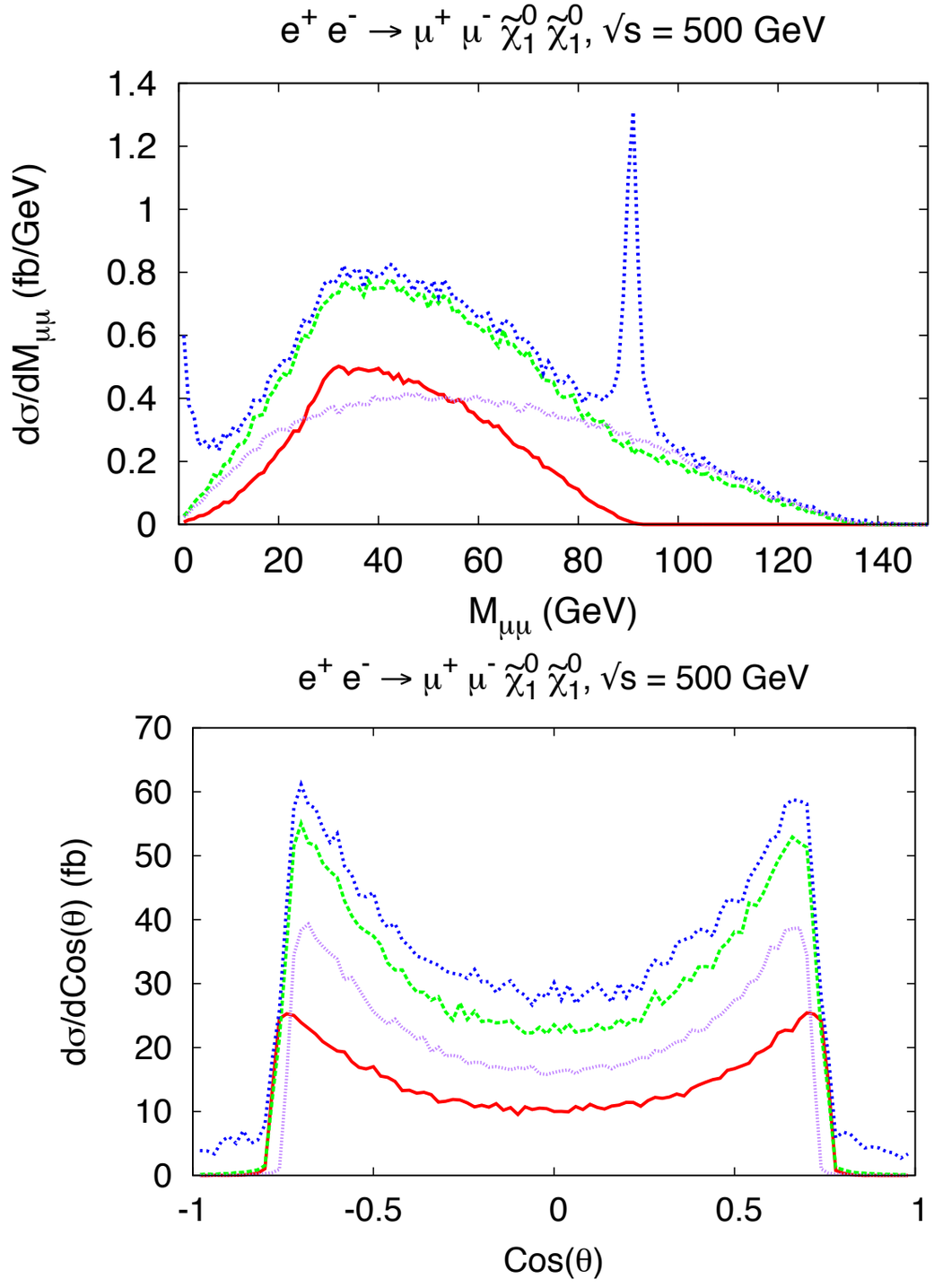
80%:60%
right polarization

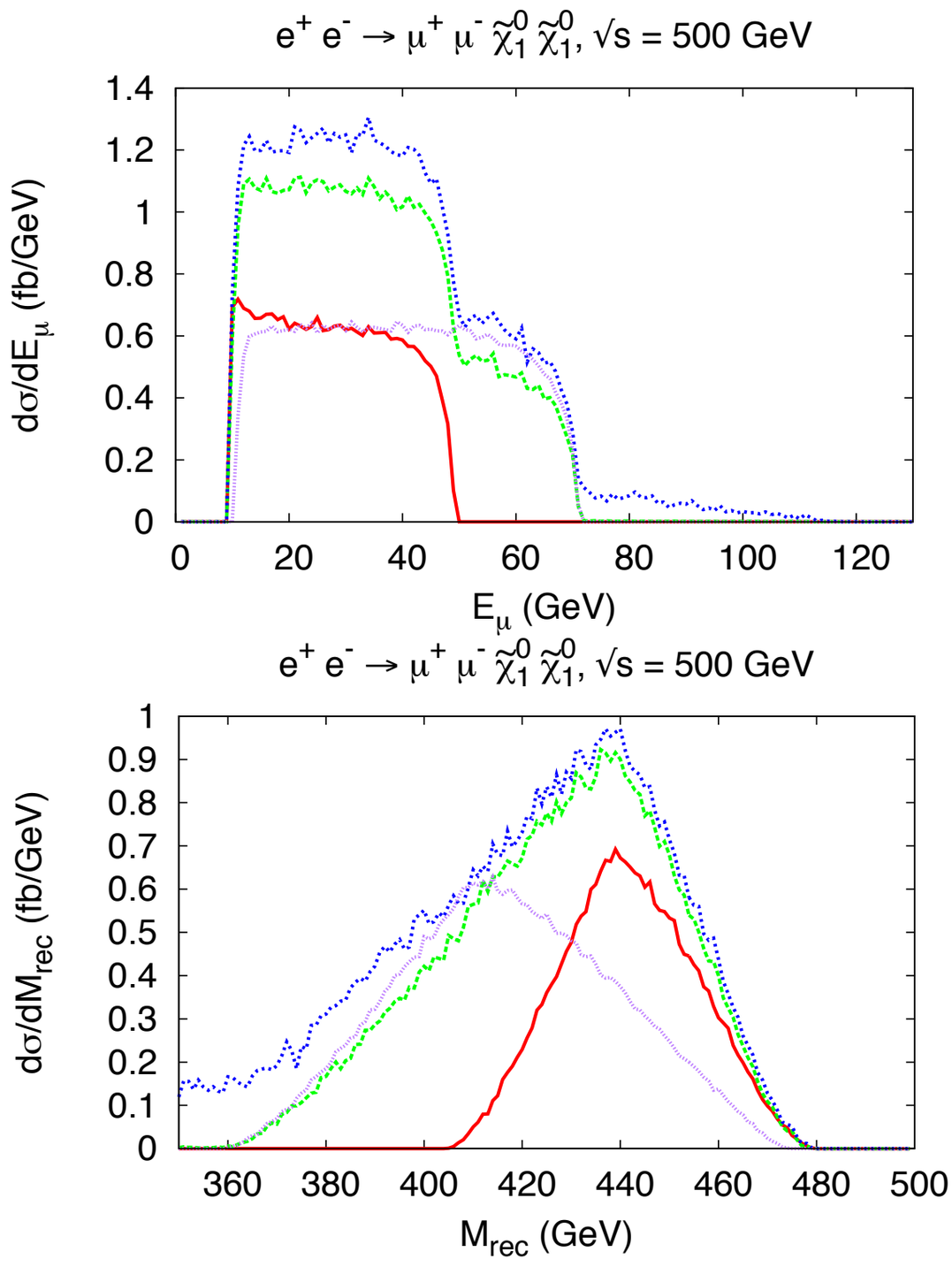


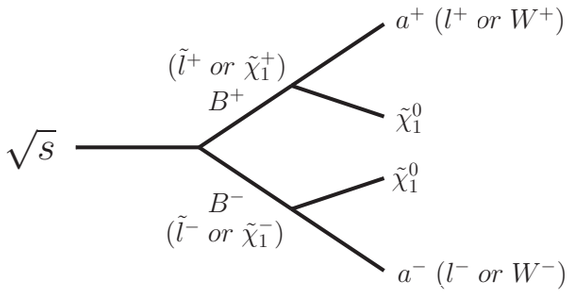




$$m_{\tilde{l}_L} \sim m_{\tilde{l}_R}$$

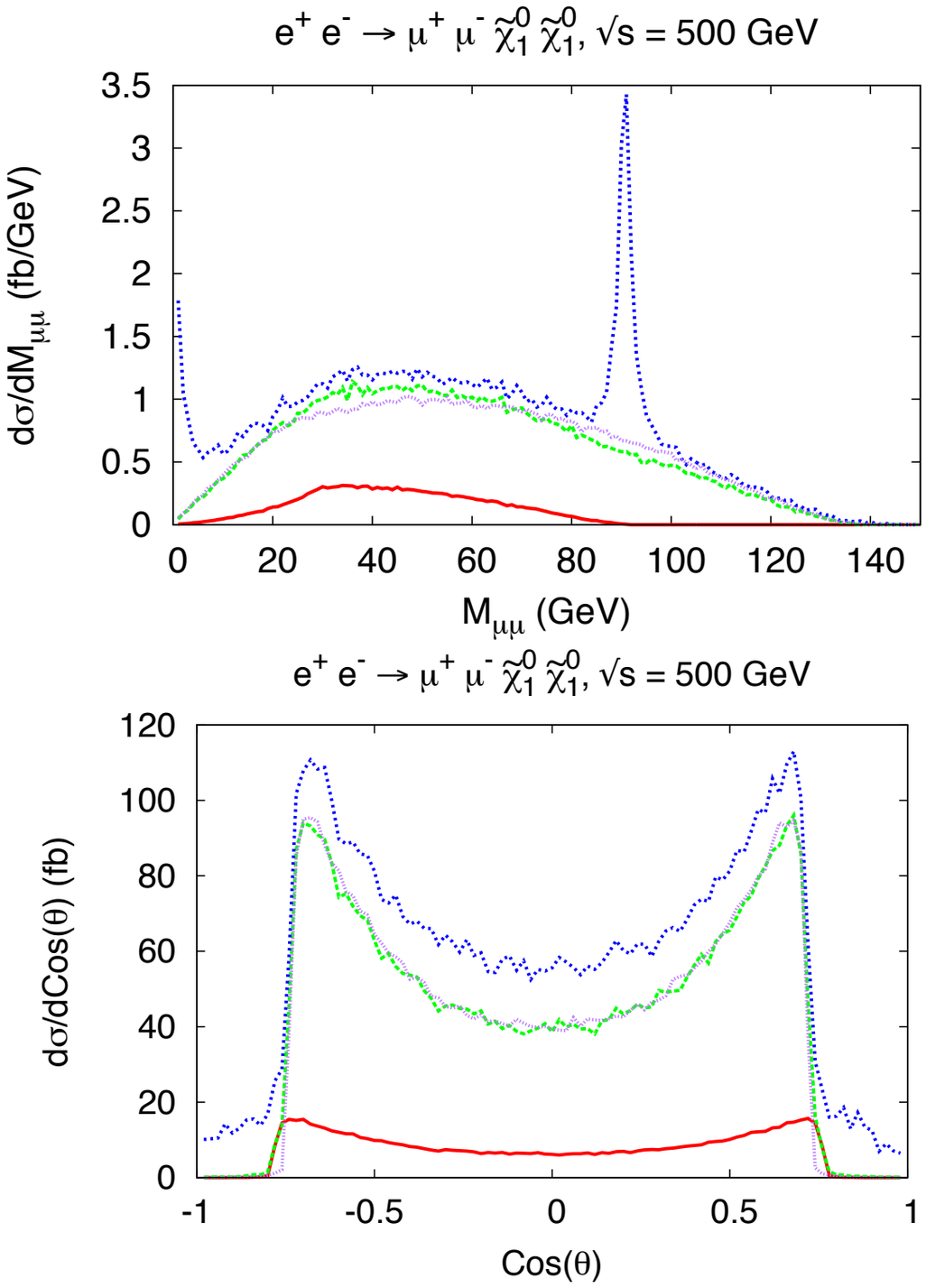


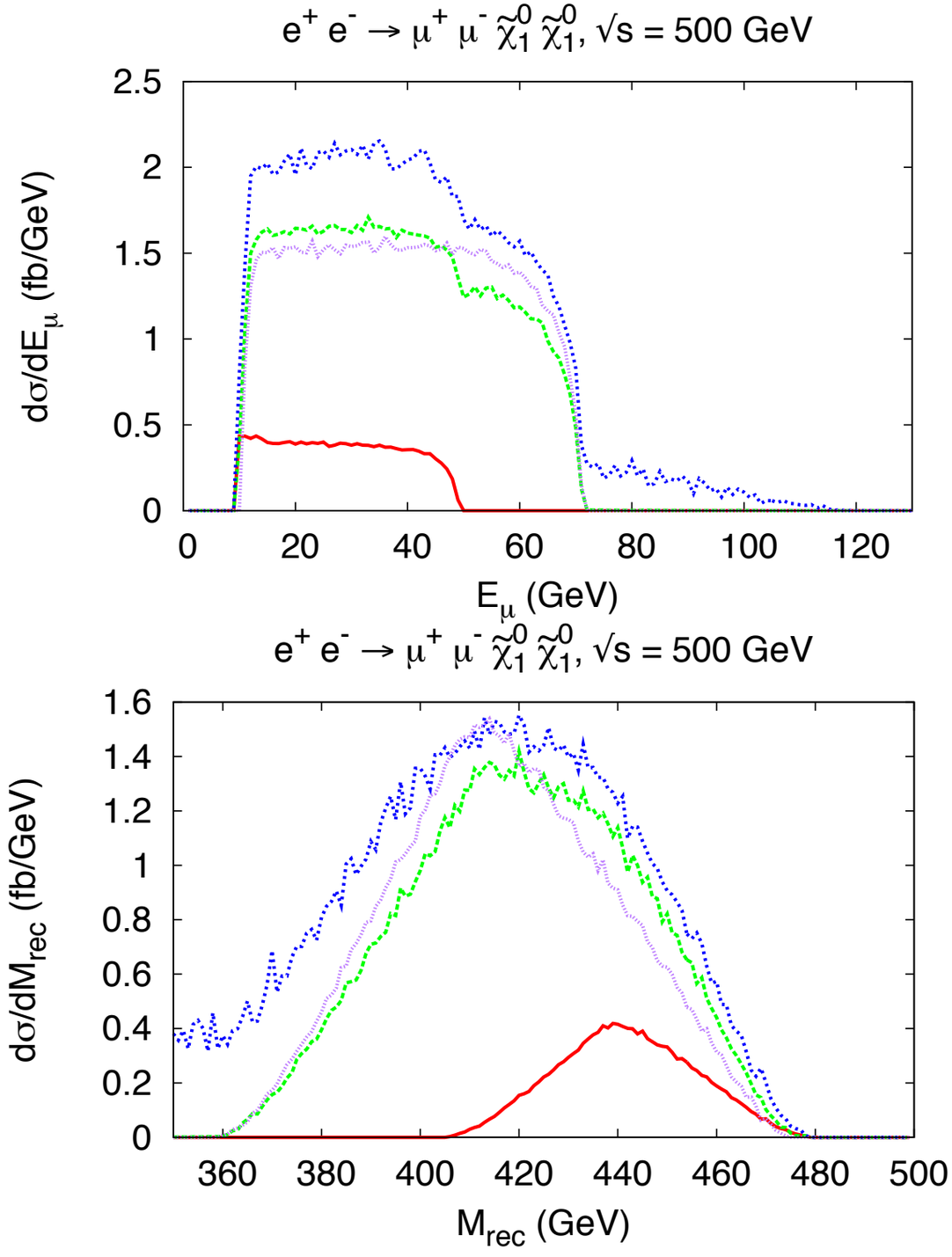




$$m_{\tilde{l}_L} \sim m_{\tilde{l}_R}$$

80%:60%
left polarization





Lepton Collider Mass Determination

- Lepton colliders provide a known collision frame.
  - m_{rec} can be used to remove most of the SM background.
  - cos θ endpoints not significantly smeared.
- Cusps and end points of kinematical variables of Antler diagrams give good mass measurement.
  - Improve on E_a endpoints, especially if E_{amin} is too small to be measured.
- Polarization can distinguish between $\tilde{l}_L$ and $\tilde{l}_R$ even if close to each other (in addition to further suppresing the SM background).

Lepton Collider Spin Determination

$$\langle j, m', \theta | j, m \rangle = d^j_{m,m'}(\theta)$$

- What we would really like is to measure the Wigner d-functions directly.
  - Dark matter particles missing: not enough information.
- If we know the masses of the particles in the Antler diagram:
  - 8 unkowns : 8 equations : However, some quadratic : 2-fold ambiguity.
- We have discovered a new way to fully reconstruct the absolute value of the angular distribution and partially reconstruct the sign.
- To be published soon: Christensen, Salmon.